THE UNIVERSITY OF ALBERTA

PLEISTOCENE VALLEY TRAIN TERRACES ALONG THE ATHABASCA RIVER IN THE HINTON AREA, ALBERTA

by

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A THESIS

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ABSTRACT

Two large paired terraces representing the surfaces of two Pleistocene valley trains are present along the Athabasca Valley in the vicinity of Hinton, Alberta. Both valley trains were deposited and terraced during the retreat of the Cordilleran Obed Glacier, an expanded toe-valley glacier that was the last to occupy the area.

Study of the surficial deposits and interpretation of the glacial history were needed in order to understand the origin of these valley train terraces. The upper valley train was the first to be deposited and it is related to a recessional moraine of the Obed Glacier within the study-area. The rapid retreat of the Obed Glacier from this moraine provided large quantities of meltwater which trenched the upper valley train into paired terraces. The lower valley train was deposited in front of the Obed Glacier when it maintained an undetermined position upstream from the study-area. Further retreat of the glacier resulted in dissection of the valley train and formation of the lower valley train terrace.

ACKNOWLEDGMENTS

The writer is indebted to M.A. Roed and Dr. L.A. Bayrock, Research Council of Alberta, for their valuable suggestions in the interpretation of the glacial deposits and history of the study-area.

Professors K.V. Abrahamsson and A.H. Laycock of the University of Alberta, Edmonton, made many helpful suggestions during the preparation of the thesis.

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INTRODUCTION

The object of this study is to describe and interpret the large paired terraces along the Athabasca River in the vicinity of Hinton, Alberta. In order to understand the origin of these terraces the surficial deposits of the study-area had to be mapped and the glacial history interpreted.

Location, Relief and Accessibility of the Study-Area

The study-area is situated in the foothills region of west-central Alberta, between 53°17 1/2' and 53°35' North Latitude and 117°25' and 117° 47 1/2' West Longitude (see Figure 1).

The northeasterly flowing Athabasca River dissects the study-area. Ridges flanking the Athabasca River extend up to 5,000 feet elevation, producing a local relief of over 1,500 feet.

The area is accessible by railway, highway and by air transportation. The main line of the Canadian National Railway parallels the Athabasca River and railway stations have been established at Pedley, Hinton and Entrance (see Figure 2). The Edmonton-Jasper highway (Highway 16) passes through the town of Hinton, which is located 185 miles west of Edmonton and 50 miles northeast of Jasper. The settlement of Entrance is connected to Highway 16 by a three-mile long gravel road. An abandoned, but rebuilt, railway bridge over the Athabasca River at Entrance allows automobiles to reach Brûlé, about 13 miles to the southwest and to travel the Forestry Trunk Road to Grande Prairie. The southward extension of the Forestry Trunk Road leads to Nordegg and branches off Highway 16 one-half mile east of Hinton. The North Western Pulp and Power Company, which operates a pulp mill at Hinton, has constructed a network of all-weather logging roads

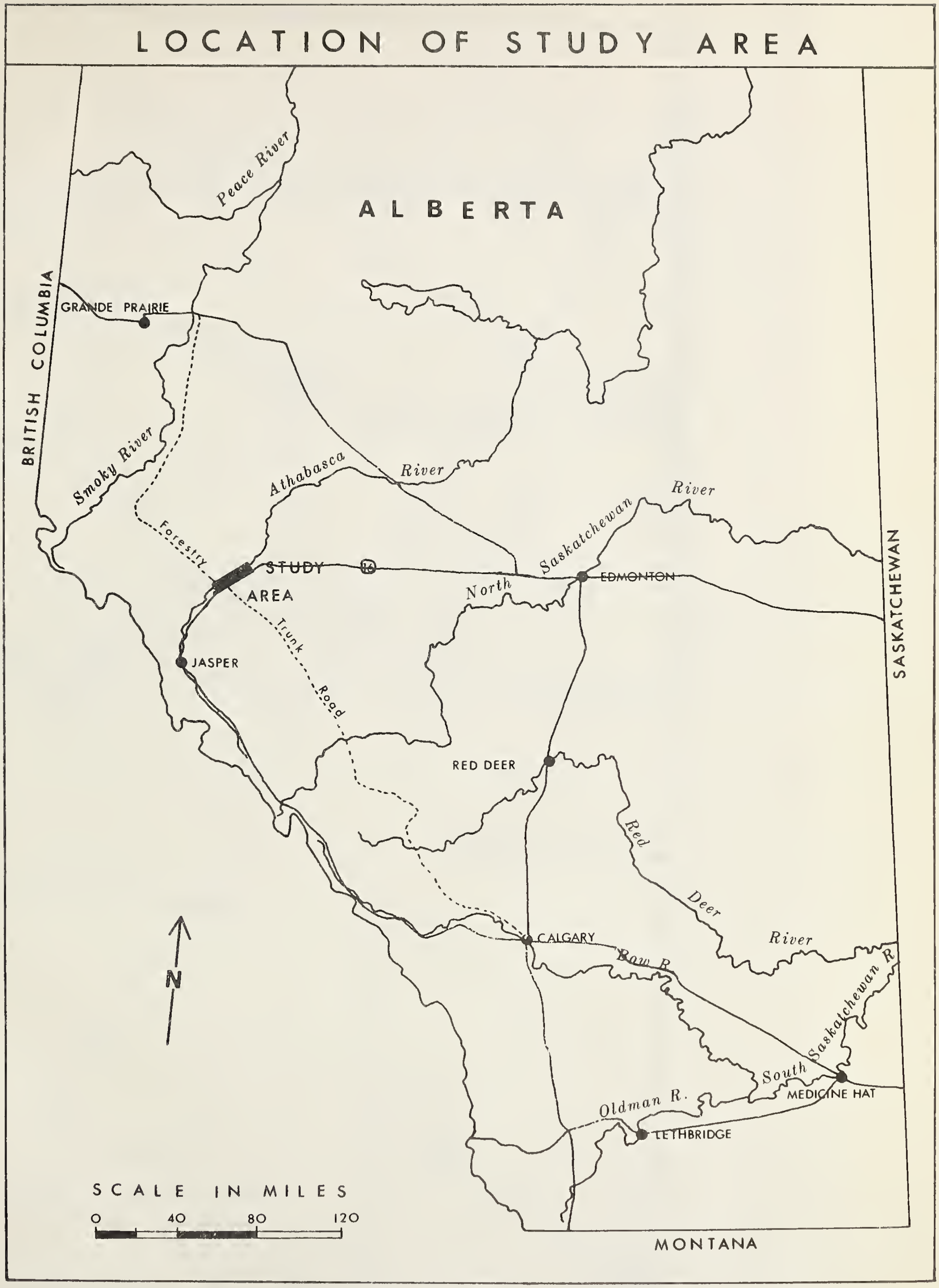
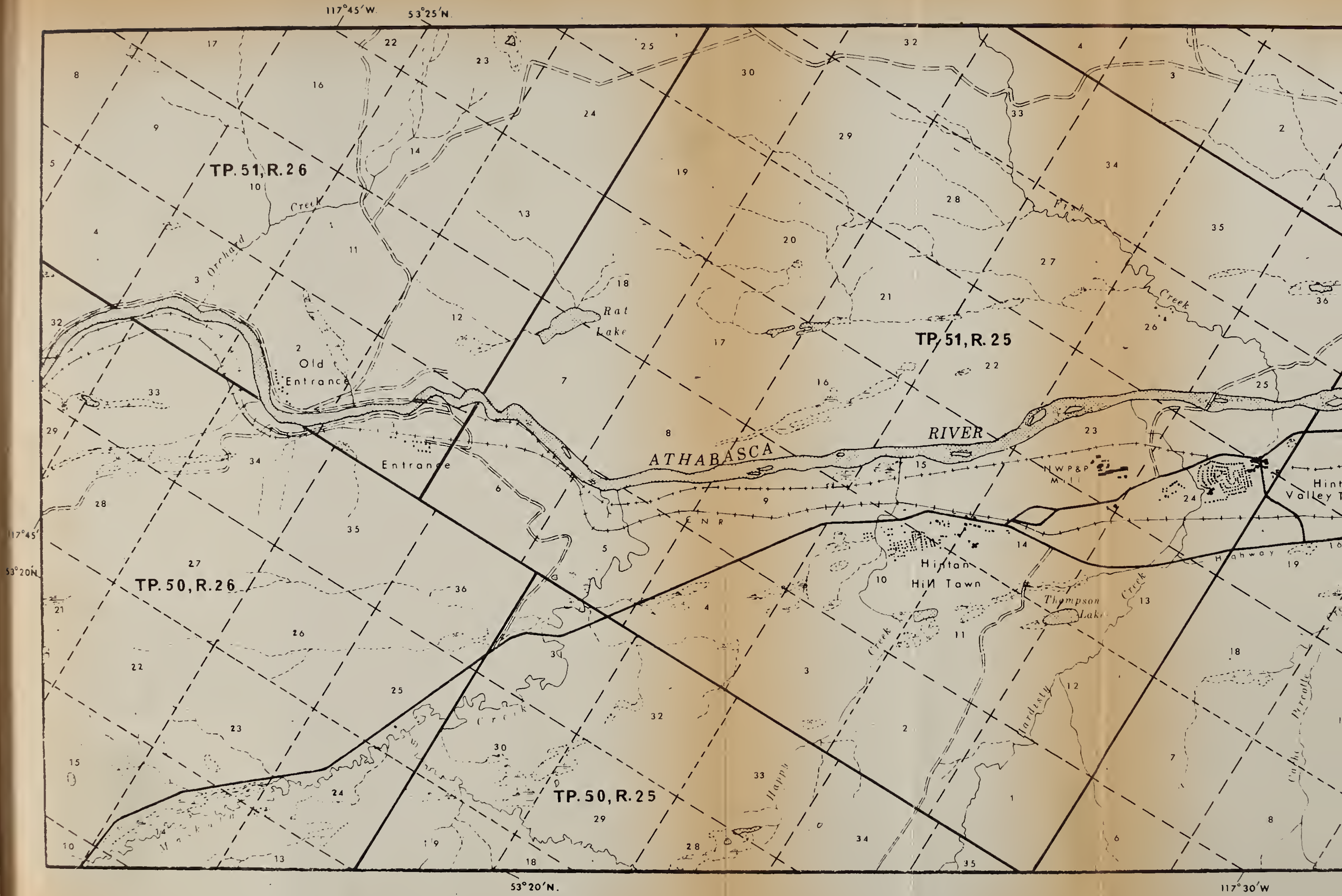

LOCATION OF STUDY AREA
ALBERTA
BRITISH COLUMBIA
SASKATCHEWAN
MONTANA
Peace River
GRANDE PRAIRIE
Smoky River
Athabasca
River
Forestry
Trunk
Road
STUDY
AREA
16
JASPER
North
Saskatchewan
River
EDMONTON
RED DEER
Red
Deer
River
CALGARY
Bow R.
South
Saskatchewan R.
MEDICINE HAT
Oldman R.
LETHBRIDGE
N
SCALE IN MILES
0
40
80
120

FIGURE I.



117°45′W.
53°25′N.
TP. 51, R. 26
TP. 51, R. 25
TP. 50, R. 26
TP. 50, R. 25
Orchard Creek
Rat Lake
Old Entrance
Entrance
ATHABASCA RIVER
Fish Creek
N W P & P Mill
C N R
Hinton Hill Town
Hint
Valley T
Highway
Thompson Lake
Creek
Hardisty Creek
Happy
Pierre
117°45′
53°20′N.
53°20′N.
117°30′W

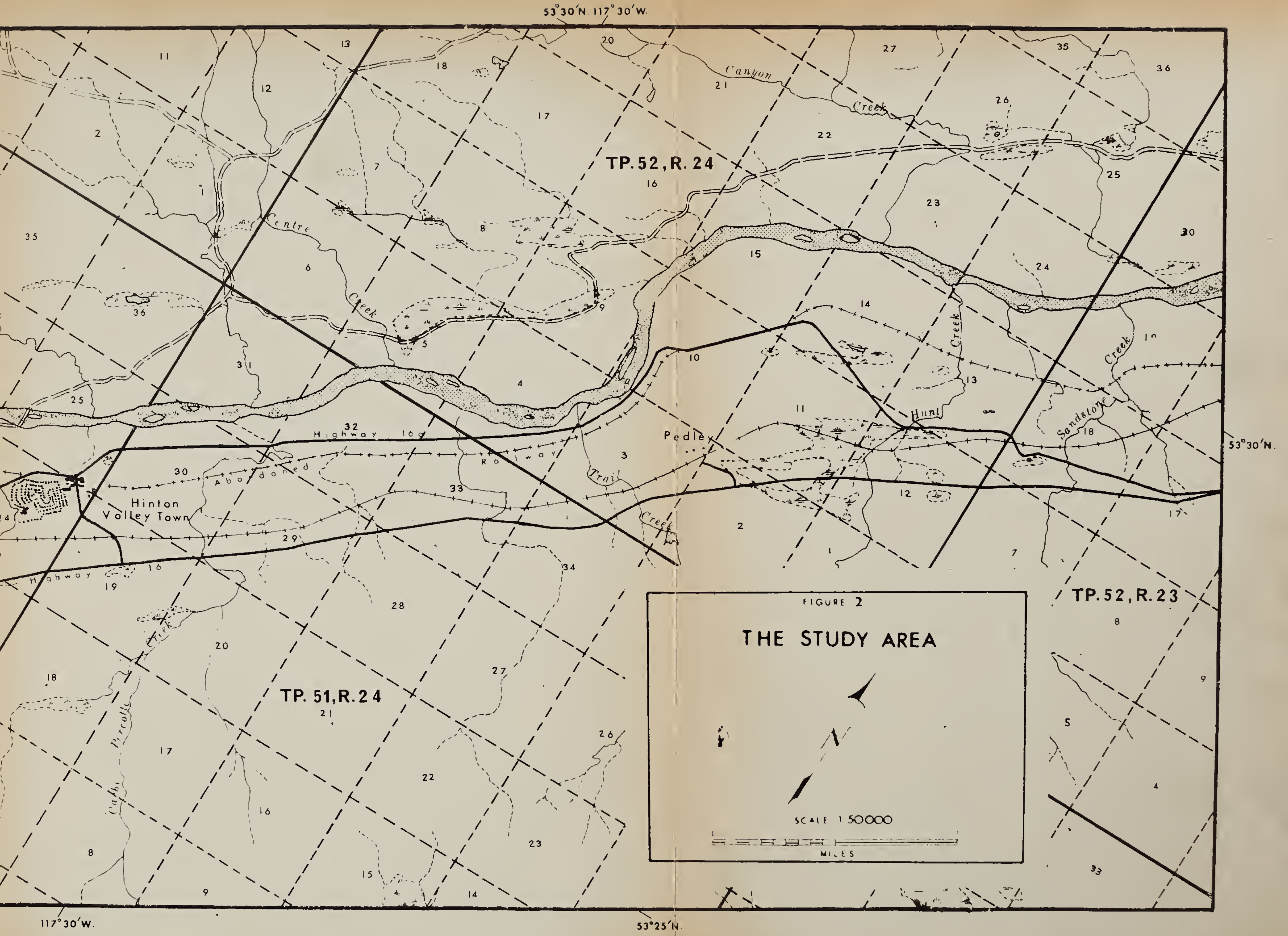


FIGURE 2

THE STUDY AREA

which permits access to most parts of the study-area. Airports are located near Entrance and Hinton and can accommodate most light planes.

Previous Work

In 1859, James Hector recognized and determined the heights of three well-marked terraces in the vicinity of present day Hinton.[1] The terraces were found to be at altitudes of 15, 100 and 210 feet above the Athabasca River, with the highest terrace known as "Le Grand Bas-fond." Mention was made of terrace remnants located 370 feet above the river. Hector was also the first to report that the Athabasca Valley had been glaciated.

In 1898, James McEvoy confirmed the glaciation of the Athabasca Valley when he recognized pebbles of Rocky Mountain origin in till on the watershed between the McLeod and Athabasca Rivers.[2] The existence of terraces along the Athabasca River in Jasper National Park led McEvoy to believe that after the retreat of ice a lake stretched from 22 miles below Brûlé Lake up the Athabasca Valley across the continental divide into the upper reaches of the Fraser River.[3]

E.M. Kindle found evidence that the Athabasca and its tributary

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[1] J. Hector in J. Palliser's The Journal, Detailed Reports, and Observations Relative to the Exploration by Captain John Palliser of that Portion of British North America, which in Latitude, Lies Between the British Boundary Line and the Height of Land or Watershed of the Northern or Frozen Ocean Respectively, and in Longitude, Between the Western Shore of Lake Superior and the Pacific Ocean During the Years 1857, 1858, 1859 and 1860, Printed by G.E. Eyre and W. Spottiswoode for H.M.S.O., London, 1863, p. 124.

[2] J. McEvoy, "Geology and Natural Resources of the Country Traversed by Yellowhead Pass Route from Edmonton to Tête Jaune Cache," Canada, Geological Survey Annual Report, 1898, Part D, 1901, p. 11D.

[3] Ibid., p. 42.

valleys were extensively glaciated. He believed that ice covered all but the highest peaks surrounding the Athabasca Valley in Jasper National Park.[4] Kindle also believed that a lake, which he called Miette Lake, occupied the Athabasca Valley following the retreat of the last glacier from the valley.[5] B.R. MacKay briefly described the glaciation of the Brûlé Mines area in a Geological Survey of Canada Report.[6] R.S. Taylor, in an article on Albertan Pleistocene lakes, suggested that the terraces of the study-area were built along the shore of Lake Miette.[7]

E.W. Mountjoy in a more recent study of the surficial geology near the study-area discounted most of the stages of Lake Miette that had been proposed in earlier studies.[8] He considered many of the terraces along the Athabasca Valley to be modified moraine or kame terraces and not lake terraces.

Present Study

The field work for this study was conducted mainly during the summer of 1964. Most of the study-area is accessible by road, and transportation

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[4] E.M. Kindle, The Geological Story of Jasper National Park, Canada, Department of the Interior, National Parks of Canada, Ottawa, 1929, p.30.

[5] Ibid., p. 32.

[6] B.R. MacKay, "Brûlé Mines Coal Area, Alberta, Canada," Geological Survey of Canada, Summary Report, 1928, Part B, Ottawa, 1929, pp. 4B-5B.

[7] R.S. Taylor, "Some Pleistocene Lakes of Northern Alberta and Adjacent Areas (Revised)," Journal of the Alberta Society of Petroleum Geologists, Vol. 8, No. 6, June, 1960, pp. 169-170.

[8] E.W. Mountjoy, unpublished manuscript that will form part of a forthcoming Geological Survey of Canada Memoir on the Miette Map-Area, 1964.

for field work was provided by jeep. Many of those areas not accessible by road were traversed on foot. Road-cuts, railway-cuts, river cut-banks and dug holes provided data on the stratigraphy of the unconsolidated deposits.

Aerial photographs on the scales of 1 inch to 3,333 feet and 1 inch to 2,640 feet from the Alberta Department of Lands and Forests were used extensively in the interpretation of glacial features and in delimiting the boundaries of the various deposits.

Because the major topographic control for the study-area was derived from maps with 100-foot contours, the terraces were mapped and correlated by careful stereoscopic study of the aerial photographs. Elevations on the major terrace treads were determined by means of a Paulin altimeter survey using established bench marks for control. The altimeter readings are believed to be accurate to within five feet.

CHAPTER I

STREAM TERRACES: FORMATION, GENETIC TYPES AND IDENTIFYING FEATURES

THE FORMATION OF STREAM TERRACES

Definition

A stream terrace is a bench-like landform that consists of two parts, a relatively steep scarp and a nearly flat tread above and behind it. Stream terraces border valleys and mark the level of abandoned flood plains not related to the present stream. The formation of a terrace involves the development of a flood plain and the dissection of it by the stream, leaving remnants as terraces above the new stream level.

Flood Plain Formation

A stream may form a flood plain when it approaches the graded condition, when it is gradually eroding a valley, or when it is depositing a fill.[1] The graded condition is attained by the stream when "over a period of years, slope is delicately adjusted to provide, with available discharge and with prevailing channel characteristics, just the velocity required for the transportation of the load supplied from the drainage basin."[2]

In larger and longer streams some stretches may be actively eroding or depositing, while others are at grade. Changes in hydrologic regimen, be-

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[1] M. G. Wolman and L.B. Leopold, River Flood Plains: Some Observations on Their Formation, U.S. Geological Survey Professional Paper 282-C, Washington, D.C., 1957, p. 105.

[2] J.H. Mackin, "Concepts of the Graded River," Geological Society of America Bulletin, Vol. 59, 1948, p. 471.

cause of tectonic, climatic and bedrock conditions, will cause the stream to adjust to a new equilibrium. If the changes are gradual enough so that adjustment can keep pace, the flood plain will be maintained.

A flood plain consists of two fundamental types of deposits: the point bar and the overbank deposits. In formation of the point bar deposit the stream, by lateral accretion, deposits on the convex side of a river bend, while equally eroding on the opposite concave bank. Overbank deposits consist mainly of silt, while point bar deposits were thought originally to consist only of sands and gravels. Evidence now suggests that in a stable channel most of the flood plain silts are deposited exactly as are the point bar gravels.[3]

A stream, with a stable hydrologic regimen, will not form terraces by building up its own flood plain until flooding no longer occurs. "The flood plain can only be transformed into a terrace by some tectonic, climatic, or man-induced change which alters the regimen of the river, causing it to intrench itself below its established bed and associated flood plain."[4]

Cyclic and Non-cyclic Terraces

During periods of constant climatic and tectonic conditions, flood plains result where lateral swinging of the channel has been able to keep pace with downcutting. If disruption of the hydraulic conditions of the stream occurs, either through tectonic, climatic, or man-induced change, the stream may deepen its channel, and portions of the flood plain may remain

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[3]L.B. Leopold, M.G. Wolman and J.P. Miller, Fluvial Processes in Geomorphology, W.H. Freeman and Co., San Francisco, 1964, p. 323.

[4]Wolman and Leopold, op.cit., p. 106.

as flat or nearly flat terraces bordering the stream.

If rejuvenation occurs suddenly, streams might undergo rapid downcutting and leave terrace remnants of equal elevation on opposite sides of the valley. Such terraces are known as cyclic or paired terraces. On cessation of valley deepening lateral erosion by the stream forms a flood plain. The alternation of times of rapid rejuvenation and downcutting with times of stability and lateral erosion may result in the preservation of a series of paired terraces at different elevations along the valley sides. (See Fig. 3 A)[5]

If rejuvenation has been slow enough so that there was concomitant downcutting and lateral erosion, non-cyclic or non-paired terraces will be formed. Under these conditions a meandering stream will shift back and forth over its valley, and by the time that it has moved from one side of the valley to the other, the valley floor will have been lowered and terraces left on opposite sides will be at different altitudes.[6] (Fig. 3 B)

Both cyclic and non-cyclic terraces may exist along a valley. A composite origin is often suggested for these terraces; some being cut during slow downcutting and others during times of stability.[7] The existence of such cyclic and non-cyclic terraces in a valley is but one of many problems involved in a study of stream terraces.

Stream Terraces and Glaciation

During the Pleistocene epoch preglacial valleys often served as channels for the transportation of abundant outwash by glacial meltwaters

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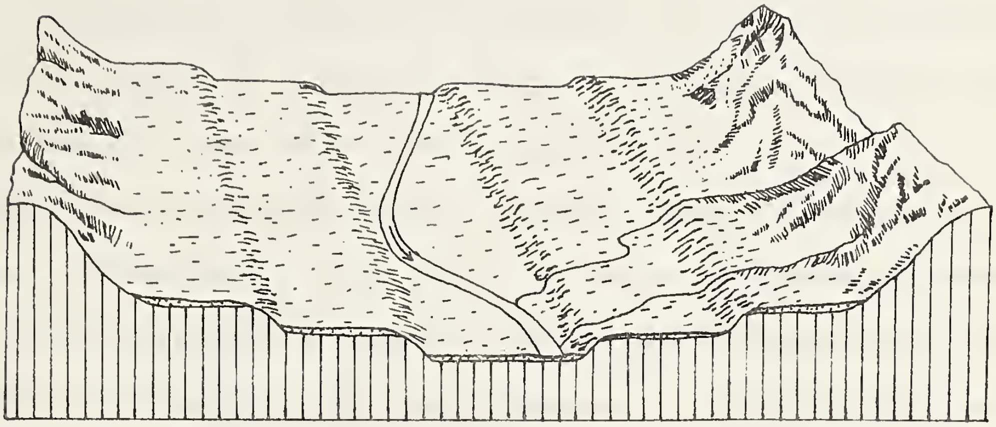
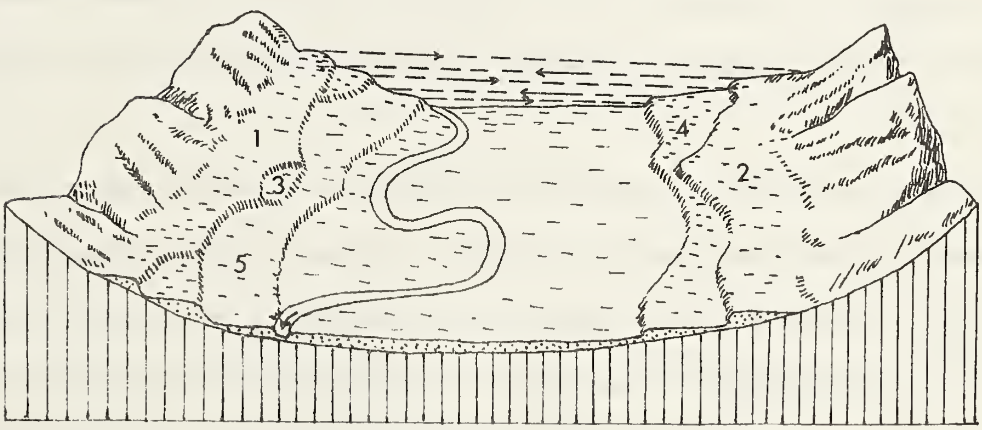
[5]A.M. Gooding, Pleistocene Terraces in the Upper Whitewater Drainage Basin, Southeastern Indiana, Indiana Science Bulletin No. 2, Richmond, Indiana, 1957, p. 11.

[6]W.D. Thornbury, Principles of Geomorphology, John Wiley and Sons, New York, 1960, p. 158.

[7]C.A. Cotton, "Classification and Correlation of River Terraces," Journal of Geomorphology, Vol. 3, 1940, p. 33.



A



B

FIGURE 3 – Diagrams showing the difference between: A, paired terraces, and B. non-poired terraces.

issuing from retreating glaciers. Although outwash was deposited during periods of ice advance it is believed to have been of small volume and was likely overridden and destroyed or buried before the glaciers reached their maximum.[8] If, however, a glacier advanced slowly for a long period of time large volumes of outwash might have been produced.

Glacial meltwaters obtain their discharge from the melting of ice within or upon the surface of the glacier. The amount of glacial meltwater is related to the regimen of the glacier. Advancing glaciers usually provide much smaller discharges than retreating glaciers. The quantity of meltwater provided by glaciers also changes diurnally, seasonally, and annually.

The discharge of glacial streams during the Pleistocene must have been much greater than the discharge of present day streams flowing in glaciated regions since known glacial outwash is coarser in grain size and also better sorted than deposits of modern streams. The coarseness and high sorting is mainly the result of diurnal flooding of glacial streams during the summer months.

Few studies have been conducted to measure the sediment load carried by meltwaters emerging from glaciers. One recent work on glacial streams shows that the meltwater acquires most of its load by eroding morainic and outwash material downstream from the glacier's terminus.[9] Whether this holds true for Pleistocene and other recent glacial streams is not known.

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[8]R.F. Flint, Glacial and Pleistocene Geology, John Wiley and Sons, New York, 1957, p. 140.

[9]R.K. Fahnestock, Morphology and Hydrology of a Glacial Stream - White River, Mount Rainier, Washington, U.S. Geological Survey Professional Paper 422-A, Washington, 1963, p. 19.

After leaving the ice, glacial meltwaters soon became overloaded and aggradation of the coarser outwash faction occurred. Transport of the outwash gravels results in diminishing size and increasing roundness of particles downstream. Outwash is often "stratified in thin courses of foreset beds, none of which has great continuity because each is partly cut away by younger beds."[10]

If outwash is deposited in a valley leading away from the ice front a long, narrow landform called a valley train is formed. Braided stream patterns existed while deposition of the outwash along the valley train was in progress. "A braided stream is one which flows in two or more anastomosing channels around alluvial islands."[11] The braided pattern itself is not evidence that the channel is overloaded, for observations support the concept that braiding is a valid equilibrium form.[12] Although the actual cause of braiding is not known, it appears that an appreciable bed load is essential for its development. From the observations and explanations of several investigators, braiding is favoured by the presence of erodible banks and fluctuations in stream discharges, two conditions which may exist in valley train formation.

Gradients of valley trains are steep, ranging from 0.5 per cent to 1 per cent in their headward parts. Valley trains often have a slightly convex cross-section as buildup of outwash is greater near the centre of the valley.[13] The headward parts of valley trains are often pitted with kettles that result

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[10]Flint, <u>op.cit.</u>, p. 137.

[11]L.B. Leopold and M.B. Wolman, <u>River Channel Patterns: Braided, Meandering, and Straight</u>, U.S. Geological Survey Professional Paper 282-B, Washington, 1957, p. 53.

[12]Leopold, Wolman and Miller, <u>op.cit.</u>, p. 294.

[13]Flint, <u>op.cit.</u>, p. 139.

from the melting-out of partially or completely buried blocks of ice. On inactive, low-gradient glaciers aggradation of outwash can begin upstream from the terminus and subsequent melting of the buried ice produces kettles.

Outwash deposits, such as valley trains, often are terraced. With retreat of the glacier the relative proportions of sediment load and water are altered. "The additional quantities of water will not only rework the previously deposited glaciofluvial sediments but will also provide sufficient flow to trench the valley alluvium, thereby creating a terrace."[14] Another process whereby terraces are formed in outwash material is described by Ray.[15] He suggests that a slight retreat and lowering of the surface of a glacier at the head of an outwash mass would result in trenching of the outwash. With shrinkage of the glacier an ice-marginal lake is created behind the outwash. This lake serves as a settling basin in which meltwaters leaving the glacier are clarified. The overflow from the lake being underloaded easily erodes the outwash producing paired terraces. A nonglacial stream, carrying a load brought from further up the valley will carve an outwash mass slowly. Degradation by such a stream will produce non-paired terraces.

Repetition of valley train formation and terracing often leads to the preservation of a sequence of terraces within a valley. Sometimes these terraces can be correlated with the appropriate glacial advances by tracing them upstream to end moraines. It was the study of terraced valley trains extending down from the Alps that led Penck and Brückner to the recognition of four stages of glaciation.[16]

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[14] Leopold, Wolman and Miller, op.cit., p. 476.

[15] L.L. Ray, "Some Minor Features of Valley Glaciers and Valley Glaciation," Journal of Geology, Vol. 43, 1935, p. 305.

[16] F.E. Zeuner, "The Pleistocene Chronology of Central Europe," Geological Magazine, Vol. 72, 1935, p. 353.

GENETIC TYPES OF STREAM TERRACES

Flood plains as noted previously can be produced by graded, gradually degrading and aggrading streams. Consequently terraces can be classified according to the origin of the flood plain from which they are derived.[17]

The first type of terrace is one formed from dissection of a flood plain by a stream that maintained the graded condition for a long period of time. Lateral corrasion of the stream has deposited a sheet of alluvium of variable thickness over bedrock or older alluvial fill. The terraces produced are cyclic and may be preserved if meandering by the stream on the present flood plain has not destroyed them. Cotton has referred to these types of terraces as "valley-plain" terraces.[18] They are also known as "cut" terraces and the development of such terraces is indicated in diagrams A and B of Figure 4.

A second type of terrace is the remnant of a flood plain formed by a degrading stream. If degradation, through changes in the hydrologic regimen of the stream, results in abandonment of the flood plain either cyclic or non-cyclic terraces may develop. Cyclic terraces can be produced by relatively fast degradation while non-cyclic terraces are formed by slower degradation. Terraces formed by rapid stream degradation in weak material, such as glacial till or alluvium, have been called "scour" terraces.[19] The term "scour" describes the surface of the terrace. Figure 4 C and D illustrates the development of such a "scour" terrace.

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[17] Gooding, op.cit., p. 13.

[18] C.A. Cotton, Landscape, Whitcomb and Tombs, Christchurch, New Zealand, 1948, p. 191.

[19] Gooding, op.cit., p. 14.

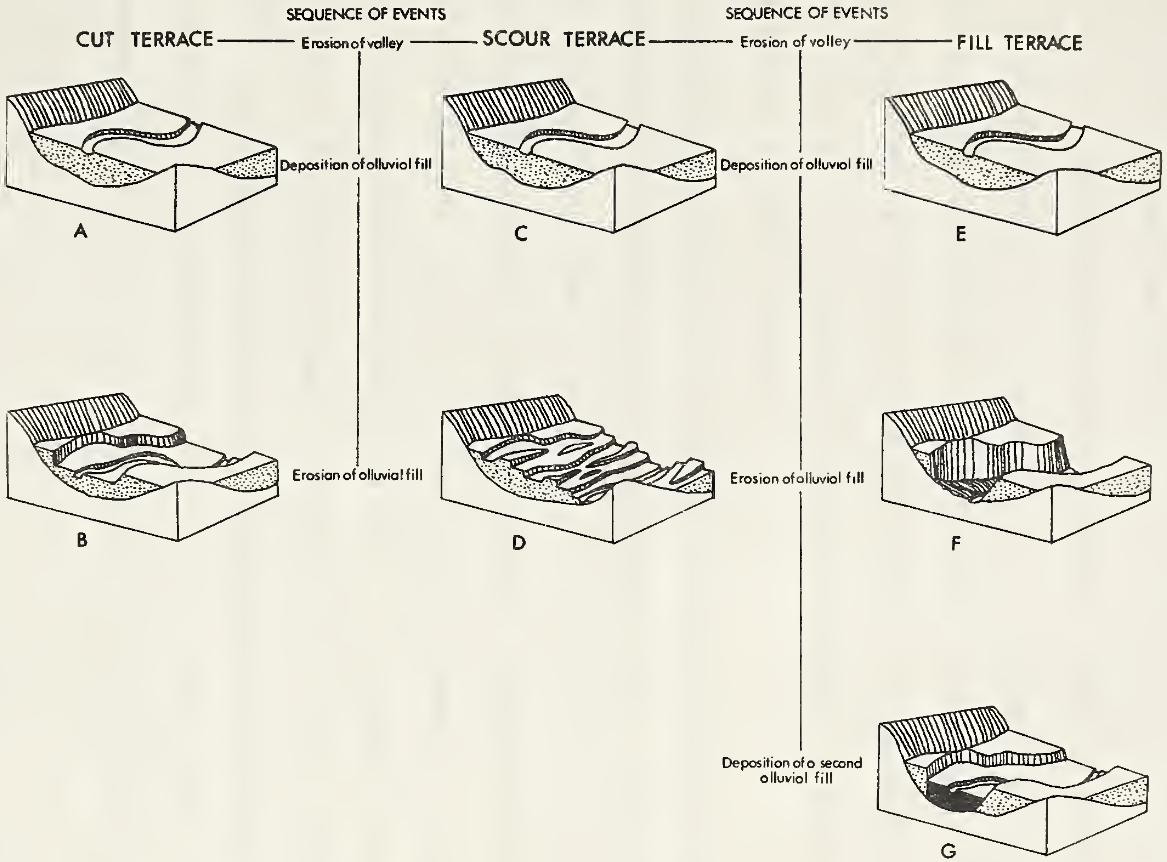

Figure 4 – Block diagrams illustrating the stages in development of a cut terrace (diagrams A and B), a scour terrace (diagrams C and D) and a fill terrace (E, F, and G).

Source: Modified from L.B. Leopold and J.P. Miller, 1954, p.4.

Terraces may also be remnants of flood plains formed by aggrading streams. Thick deposits of alluvium, such as valley trains, are built up by aggrading streams shifting across their flood plains while continually building up their channels to steeper gradients. Alluvial fill is the term used to describe deposits of unconsolidated river-laid material in a stream valley.[20] It implies that the mass of material was deposited during a nearly uninterrupted period of aggradation. Terraces that are remnants of such alluvial fills are known as "fill" terraces, and any number of these may be present in a valley, depending on the magnitude and sequence of deposition or erosion of alluvial fills. Diagrams E, F and G of Figure 4 show the stages of development of a "fill" terrace.

The stratigraphic relations of alluvial deposits are further complicated by the presence of "inset" and "overlapping" fills. "Inset" fills imply that following deposition of a first alluvial fill there was erosion, followed again by deposition of a second fill that only partly filled the valley. (For example see Figure 4 G) In the development of an "overlapping" fill partial erosion of the first fill is followed by deposition of a second fill of sufficient volume to overflow the first, followed again by erosion.[21] It is readily apparent that where there are several fills and several terraces the possibilities of complex stratigraphic relations are great, especially if any of the fills inset or overlap preceding fills.

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[20]L.B. Leopold and J.P. Miller, A Postglacial Chronology for Some Alluvial Valleys in Wyoming, U.S. Geological Survey Water-Supply Paper 1261, Washington, 1954, p. 4.

[21]*Ibid.*, p. 6.

IDENTIFYING FEATURES OF GENETIC TYPES OF STREAM TERRACES

Surface Features and Deposits

Since stream terraces are the eroded remnants of flood plains, their aerial-photographic characteristics are almost identical with those of flood plains.[22] There are, however, major differences in landform and erosion pattern.

Most stream terraces have the typical flat-topped and scarped-terrace landform. The steepness of the scarp face depends on the textural composition and stratification of the terrace deposit. Normally, granular deposits such as outwash have steep scarp faces whereas gentler scarps develop on finer-grained materials.

Terraces, because of their elevations, often undergo gully erosion along the scarp face. The nature of terrace deposits determines the degree of erosion and the gully pattern. Gullies carved in granular materials are short, narrow, moderately shallow and steep at their head end. Long, wide, shallow and swalelike gullies are typical of those formed in fine-grained material.

Surface drainage is often absent on terraces, because of the generally porous nature of the deposits. However, abandoned channel patterns may be discernible on terrace remnants. Abandoned channels often are filled with organic material and are recognized on aerial photographs by the darker grey tones. The presence of a braided stream pattern sometimes indicates that the terrace surface was once a flood plain formed by an aggrading stream. In certain instances surface drainage is present on terraces. Tributary streams

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[22] D. R. Lueder, Aerial Photographic Interpretation: Principles and Applications, McGraw-Hill Book Co., New York, 1959, p. 146.

often develop alluvial fans on terraces and occasionally these become so extensive that piedmont alluvial plains have formed upon the terrace surface. Alluvial fans are easily recognized by their radial drainage pattern and topographic form.

The surfaces of "scour" terraces are often marked by elevated alluvial "islands" (see Figure 4 D). These "islands" are remnants of an alluvial fill that has undergone degradation. Where alluvial islands exist on a "scour" terrace degradation of the alluvial fill appears to have been rapid for such islands could not be maintained for long on a degrading flood plain.

Lake sediments often occur along tributary valleys adjoining main valley terraces composed of coarser alluvium. If the main valley was once occupied by glacial meltwater streams it is evident that the terrace level is the surface of a valley train and that the lacustrine material was deposited in the tributary lakes dammed behind the valley train material.[23] Further proof is given where the altitude of the lacustrine deposits of these tributary lakes decrease downstream in accordance with the gradient of the valley train.

The existence of kettle holes on the surface of a river terrace usually indicates that aggradation of outwash over stagnant or nearly stagnant ice masses occurred during the development of a valley train. The pitted terrace does not, however, necessarily represent the valley train surface. Degradation of the valley train shortly after its formation might uncover buried ice blocks and after these melted out, kettles would be represented on both the valley train and degradational "scour" surfaces. "The existence of a single large kettle on terraces of both levels, extending across the interterrace scarp, is evidence that ice from only one stagnant ice sheet formed

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[23]Gooding, op.cit., p. 17.

the kettles, and that the interval between the stages of aggradation and degradation was both short and cold."[24]

Internal Features of Terraces

Terrace deposits viewed in cross-section along road-cuts, gravel pits and river banks often have internal features that suggest the mode of origin of the former flood plain.

When a relatively thin layer of channel gravels rests upon bevelled bedrock of varying resistance it can be concluded that the planation surface was formed by lateral accretion of a graded stream over a long period of time.[25] Upon material that is easily erodible, such as glacial till or outwash, a thin layer of channel gravels can either be built up rapidly by a degrading stream or built up slowly by a graded stream.[26] If a cross-section view of a river terrace shows coarse-grained, well sorted material with occasional short, truncated cross-beds it is reasonable to assume that the material is glacial outwash and that the terrace probably represents the surface of a valley train.

In aggrading streams, such as those that deposit glacial outwash, the bed load is continually being dropped out with grain size decreasing in the downstream direction. Mackin states that the downstream decrease in grain size is much more rapid in an aggrading stream than in either a graded stream or a degrading stream nearly at grade.[27] If enough exposures exist downstream along a terrace scarp, a study of the rate of decrease in grain size

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[24] Loc. cit.

[25] Mackin, op.cit., pp. 472-473.

[26] Gooding, op.cit., p. 14.

[27] Mackin, op.cit., pp. 505-506.

of channel deposits might give information regarding the regimen of the stream that deposited the terrace materials.

Summary

It is hoped that future research on terraces will develop a better understanding of these interesting landforms. The chapter has been an attempt to classify stream terraces according to their mode of origin as a contribution to this specific field.

CHAPTER II

PHYSICAL CHARACTERISTICS OF THE STUDY-AREA

TOPOGRAPHY

The major topographic feature of the study-area is the Athabasca Valley. This valley is believed to be of preglacial origin for it is more than 10 miles wide and entrenched nearly 2,000 feet below the flanking divide areas.

Glaciation has modified the major elements of the preglacial topography. Within the study-area the Athabasca Valley has been deepened 200 to 300 feet by glacial erosion. This conclusion has been gained from evidence in the valleys of Maskuta and Canyon Creeks. Here, post-glacial streams in attempting to reach the local base-level of the Athabasca River have undergone headward erosion and formed deep canyons in bedrock at their mouths.

The two large paired terraces in the study-area are major topographic features which have resulted from glaciation. The topography of these terraces is flat to gently undulating and the surficial sediment is glacio-fluvial sand and gravel, covered by a thin mantle of aeolian sand. Further up the Athabasca Valley slopes, the topography is rolling to strongly rolling and the surface sediment is composed mainly of till.

The geomorphology of the glacial and recent deposits in the study-area is described in Chapter III.

DRAINAGE

The entire study-area is drained by the Athabasca River, which eventually flows to the Arctic Ocean. The tributary drainage to the Athabasca River is roughly rectangular in pattern, the tributaries being mainly controlled by the attitude and the structure of the bedrock.

GEOLOGY

Stratigraphy

The study-area is underlain by marine and non-marine sedimentary strata ranging in age from early Upper Cretaceous to Paleocene. The sedimentary strata were deposited along the eastern flank of the Cordilleran Geosyncline.[1] The geologic formations exposed in the study-area are listed in Table I.

TABLE I - GEOLOGICAL FORMATIONS, HINTON AREA

Era	Period or Epoch	Formation and Approximate Thickness in Feet	Lithological Subdivisions	Lithology
Cenozoic	Paleocene	4,500		Sandstone, Conglomerate, Shale, Coal
			Entrance Member, 20	Conglomerate
Mesozoic	Upper Cretaceous	Brazeau 6,000 ±		Sandstone, Shale, Conglomerate (non-marine)
			Solomon Member, 95	Sandstone
		Wapiabi 1,600 ±		Chiefly Black Shale (marine)

Source: A.H. Lang, Canada Geol. Survey Memoir 244, 1947.

a. Upper Cretaceous Series

i) Wapiabi Formation. The Wapiabi Formation is exposed through faulting in a thin band in the southwest corner of the study-area (see Figure 5). This formation consists mostly of soft, black marine shales with some sandy shale and thin siltstone beds.

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[1] A.H. Lang, Brûlé and Entrance Map-Area, Alberta, Canada, Geological Survey of Canada, Memoir 244, Ottawa, 1947, p. 11.

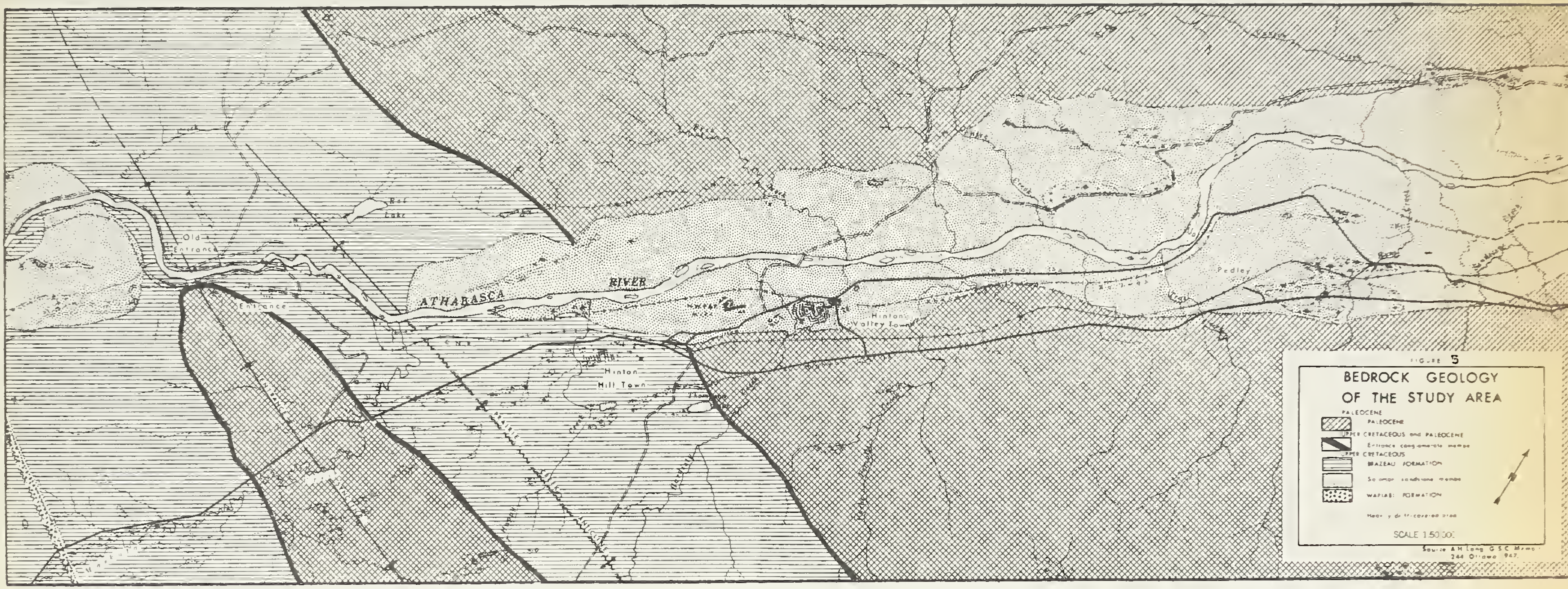

FIGURE 5
BEDROCK GEOLOGY OF THE STUDY AREA

ii) Brazeau Formation. The Wapiabi shales are overlain conformably by the non-marine Brazeau Formation. The lower 95 feet of this formation consists of hard, fine-grained sandstone and has been termed the Solomon Member. The rest of the Brazeau Formation consists of interbedded sandstone, shale and pebble-conglomerate with a few coal seams.

b. Paleocene Series

Bedrock of Paleocene age is the most widespread in the study-area. The Brazeau Formation is overlain conformably by the 20-foot thick Entrance Conglomerate Member. Overlying this member is a thick succession of relatively soft, interbedded sandstone and shale beds, with minor conglomerate beds, bentonitic beds and coal seams.

Structure

The Rocky Mountains and the adjacent foothills are the result of a period of uplift, folding, and faulting known as the Laramide Orogeny, that began during mid-Tertiary time.

The deformation in the foothills and Rocky Mountains increases from east to west. Along the eastern foothills, where the study-area is located, open folds with minor faults prevail. Towards the west more intense folding and faulting occurs. The net result is the exposure of long, relatively narrow, sub-parallel ridges of strata with a northwest trend.

The major structures in the study-area are the southeast plunging Entrance Syncline and the Prairie Creek Anticline (see Figure 5).

CLIMATE

The study-area, because of its location east of the Rocky Mountains in west-central Alberta, experiences a continental climate. According to Köppen's climatic classification the climate of the study-area is Dcf; that is, a humid, microthermal subarctic climate. The climatic graph for Entrance (see Figure 6),

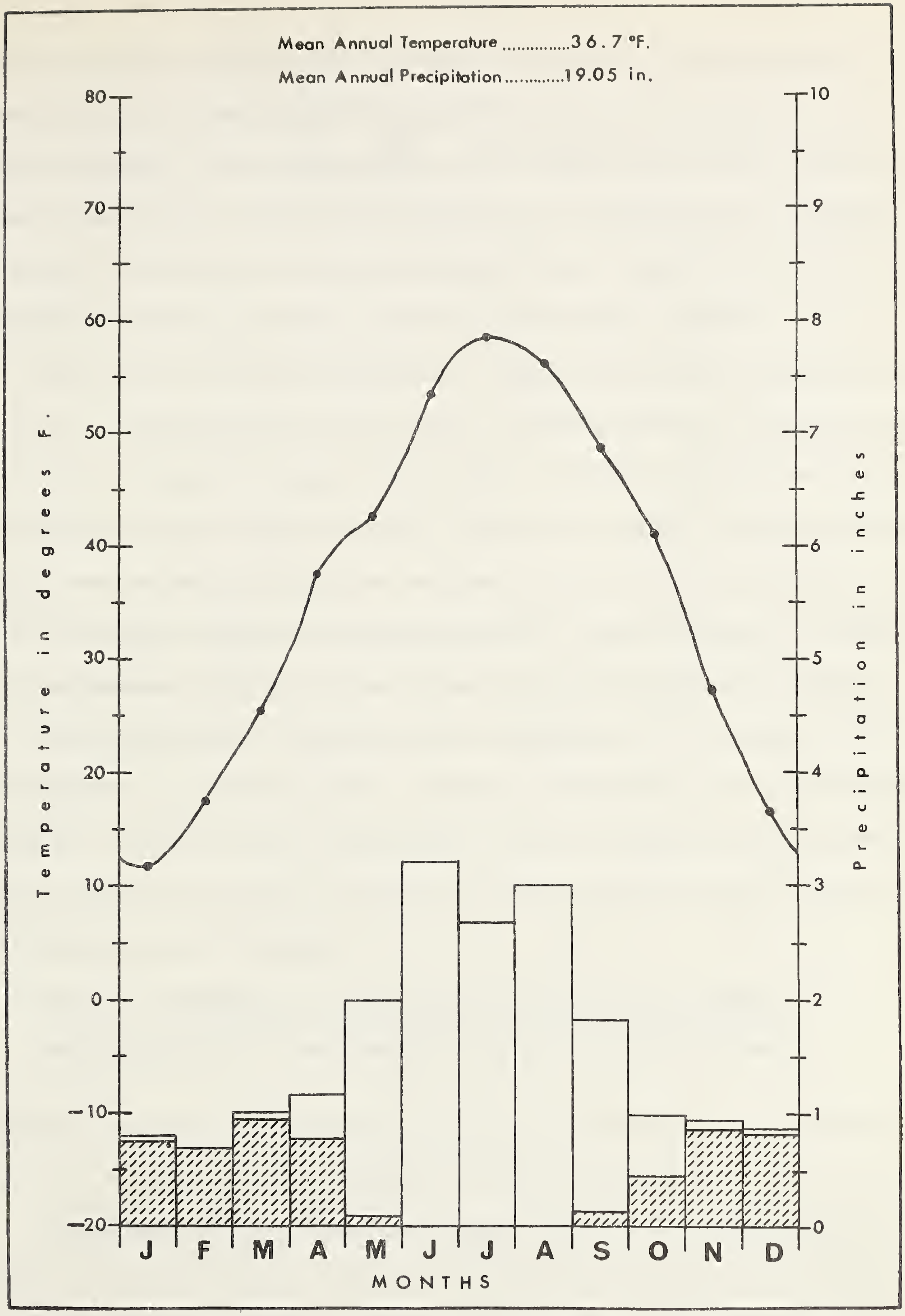

Figure 6. Climatic graph for Entrance compiled from records for the period 1921-1960. The blank bars represent rainfall; the dashed bars represent snowfall expressed as a rainfall equivalent.

Source: Canada, Dept. of Transport, Meteorological Division, Monthly Record 1921 – 1960

which is based on meteorological records from 1921 to 1960 inclusive, is representative of the temperature and precipitation of the lower part of the Athabasca Valley. The higher slopes of the valley are probably cooler and moister, but in both locations the temperature and precipitation regimen are the same. Variations in aspect, exposure, slope, elevation and other factors within the study-area, however, produce microclimatic effects.

Large annual and daily temperature ranges within the study-area illustrate the continentality of the climate. Summers are mild, with the warmest month, July, having an average temperature of 58.7°F. Winters are long and cold and the average temperature for January, the coldest month, is 11.2°F. Monthly average temperatures from one year to the next differ greatly. This may be attributed largely to the proportions of time different air masses have been present within the area in each season of successive years.[2]

The average annual precipitation at Entrance, for the period 1921 to 1960 inclusive, was 19.05 inches. Extremes of 10.9 inches and 31.0 inches occurred in 1922 and 1935, respectively. As with temperature, wide variation in monthly and yearly precipitation occur from one year to the next. These variations are dependent:

> upon the frequency of change and the duration of presence of moist air masses, and the degree to which moist marine air is subjected to orographic, cyclonic and convectional uplift.[3]

Variation in monthly precipitation can also be attributed to occasional inflow of mT air plus uplift associated with the presence of cold air aloft.

Temperature and precipitation changes can best be explained by con-

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[2]A.H. Laycock, A Physiographic Classification of Soils for Land Use Planning on the Eastern Slopes of the Canadian Rockies, unpublished Ph.D. thesis, University of Minnesota, 1957, p. 9.

[3]Ibid., p. 10.

sidering the air masses that occupy the study-area. Polar maritime (mP) air masses from the North Pacific predominate. These mild air masses lose most of their moisture in crossing the Cordilleran barrier, but still supply the major amount of rainfall and snowfall within the study-area. MP air masses undergoing orographic uplift, convectional uplift and uplift along frontal surfaces provide most of the precipitation.[4]

MP air masses in summer provide average temperatures. Inflow of mP air into the study-area in winter produces milder than normal temperatures, which rise well above normal if this air prevails for a few days. In winter mP air moving across the Continental Divide gains heat from adiabatic processes and produces the chinook. The mean winter temperatures of Hinton are normally 2 to 3°F warmer than those of Edson. The reason is that chinooks are stronger and are experienced more often at Hinton than at Edson, as the latter is located about 60 miles to the northeast from Hinton.

Polar continental (cP) air masses commonly invade the study-area. Their source is in continental Northern Canada, from where they travel southeastwards paralleling the Rocky Mountains to affect the study-area. CP air masses (and the related Arctic masses) predominate during winter and usually provide colder than average temperatures. Temperatures as low as -60°F have been recorded at Entrance. In summer cP air masses are usually cool and dry, and some are indistinguishable from mP air masses. CP air may produce below freezing temperatures in any month of summer.

The average frost-free period (the period in which the minimum temperature is 32.5°F or above) for the study-area is 48 days, measured over a 41-year period.[5] Variation from the average frost-free period is great, with

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[4] Ibid., p. 11.

[5] R.W. Longley, The Frost Free Period in Alberta, mimeo. copy, University of Alberta, Edmonton, 1965, p. 5.

extremes of 31 days and 72 days having occurred.

THE WATER BALANCE

Figure 7 shows graphs illustrating the monthly precipitation, potential evapotranspiration, soil moisture recharge, water surplus, soil moisture utilization and water deficiency at Entrance for the years 1934, 1935, 1936 and 1937 based on Thornthwaite procedures.[6] A soil moisture storage of four inches, freely usable by plants, is assumed.

The graphs of 1934 and 1935 in Figure 7 illustrate the water balance pattern for Entrance during years of large surpluses. In late March of 1934 melting snow provided only a small amount of moisture for runoff. Precipitation exceeded evapotranspiration in May and June but less than half of the excess of precipitation was available for runoff, the rest being required for recharge of soil moisture used during April and early May. Evapotranspiration exceeded precipitation in July and August, resulting in withdrawal of soil moisture but with no occurrence of a moisture deficit. In September heavy rains replenished the soil moisture and produced most of the runoff that occurred during the year.

The year 1935 was also a year of high precipitation and large runoff. Most of the precipitation and runoff occurred during the spring months. Although evapotranspiration during the summer months withdrew some soil moisture no moisture deficit occurred. High precipitation in October resulted in full soil moisture capacities, and the year ended with a small water surplus.

Precipitation at Entrance was well below average for the years 1936 and 1937. Full soil moisture capacities and average snowfall during the early

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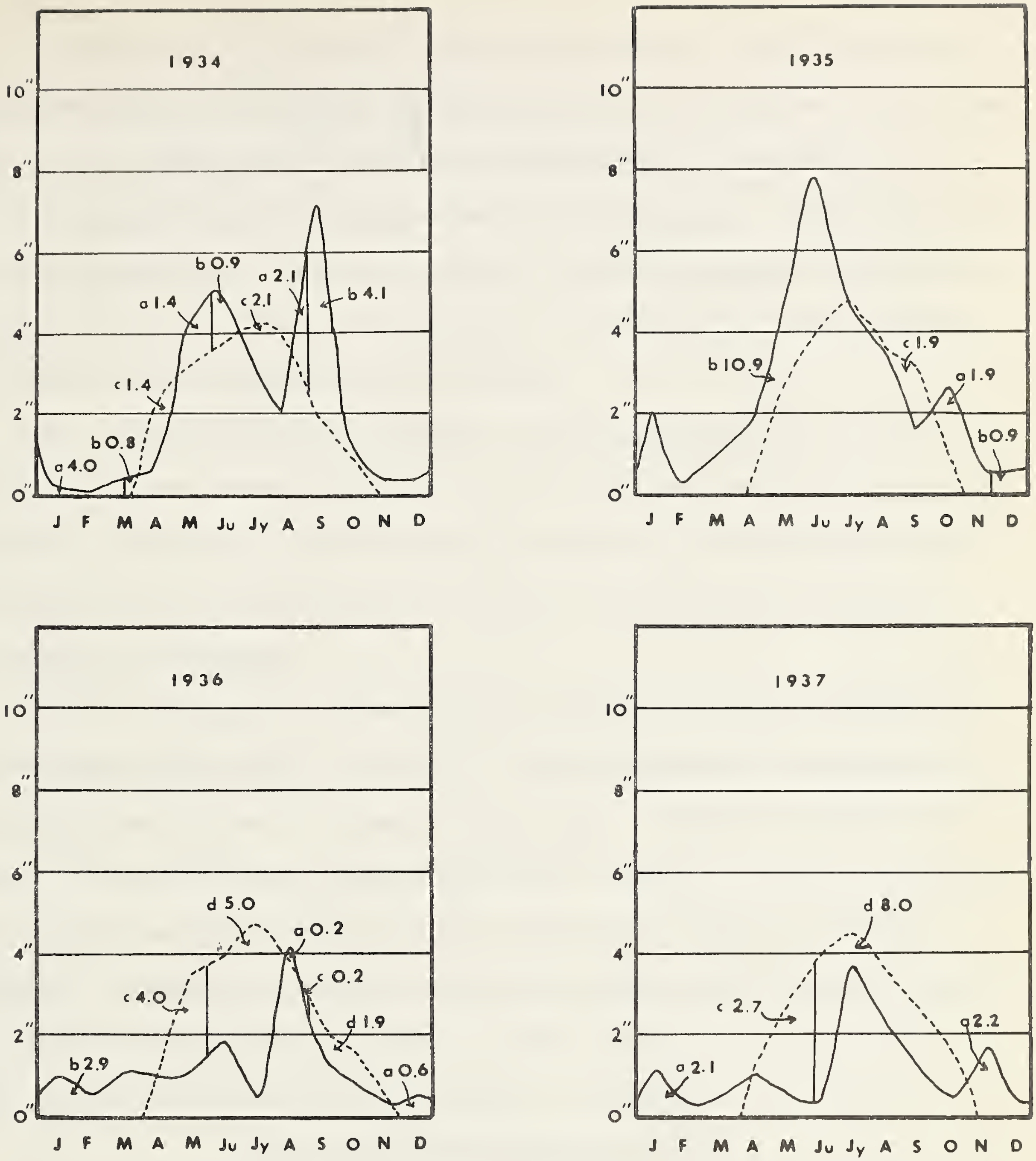
[6] C. W. Thornthwaite, "An Approach to a Rational Classification of Climate," Geographical Review, Vol. 38, No. 1, 1948, pp. 55-94.



KEY

a — Sail moisture recharge

b — Water surplus

c — Sail moisture utilization

d — Water deficiency

——— ··Precipitation

- - - - - - · Potential Evapotranspiration

Figure 7 - Graph of precipitation and evapotranspiration for Entrance for the years 1934, 1935, 1936 and 1937.

part of 1936 provided an average surplus from snowmelt in March and April. Evapotranspiration had depleted the four inches of soil moisture by the first of June and a large moisture deficit was experienced in June and July. Although there was a large amount of precipitation in August, evapotranspiration was also large, and as a result there was little replenishment of soil moisture. The moisture deficit continued until November and by year's end there was a soil moisture deficiency of 3.4 inches.

The snowfall of January, February, and March of 1937 was not enough to replenish the soil moisture capacity. By June the soil moisture had been withdrawn, and because of small summer precipitation, a large water deficit persisted until the end of October. The year ended with a soil moisture deficiency of 1.8 inches.

Table V in Appendix A gives the water balance equations for Entrance for the years 1921 to 1950, inclusive. Average surpluses and deficits over this period are 2.6 and 3.4 inches, respectively. Although the graphs in Figure 7 illustrate years having extreme water surpluses and water deficits, they do show some of the month to month variations of the water balance elements. For example, in most years water surpluses occur during the snowmelt period of late March and April. In 1934, however, over four inches of water surplus were gained from heavy rains in September.

WATER YIELD OF THE ATHABASCA RIVER

It has been shown by water balance studies based on Thornthwaite procedures that the study-area contributes only a small and variable amount of runoff to the Athabasca River. Most of this runoff occurs during the snowmelt period of late March and early April. The detention storage provided by the thicker glacio-fluvial and till deposits in the study-area allows for release of small amounts of water during the summer.

A stream gauging station on the Athabasca River at Entrance has been in operation from 1915 to 1939 and from 1955 to 1961. The data collected at this station clearly indicate the streamflow pattern of the Athabasca River within the Rocky Mountains.[7] Figure 8 shows that streamflow is low during the winter months, but increases during late spring, with the addition of snowmelt and rainfall from the Front Ranges and mountain valleys. Considerable snowmelt and some rainfall from the Back Ranges produces a peak streamflow during June and July. From August onward streamflow decreases steadily.

The regimen of the Athabasca River at Entrance is consistent year after year and variation from the average annual streamflow of 4,751,000 acre-feet is small.

Within the study-area, the Athabasca River causes little flood damage, other than to its immediate flood plain. The annual runoff of the Athabasca is so consistently high that the river has eroded its valley sufficiently to allow for most runoff conditions.

VEGETATION

The maps of forest and phytogeographic regions produced by Rowe[8] and Moss,[9] respectively, are of such scale that only the major plant communities within the study-area can be discerned. Rowe's description of the Lower

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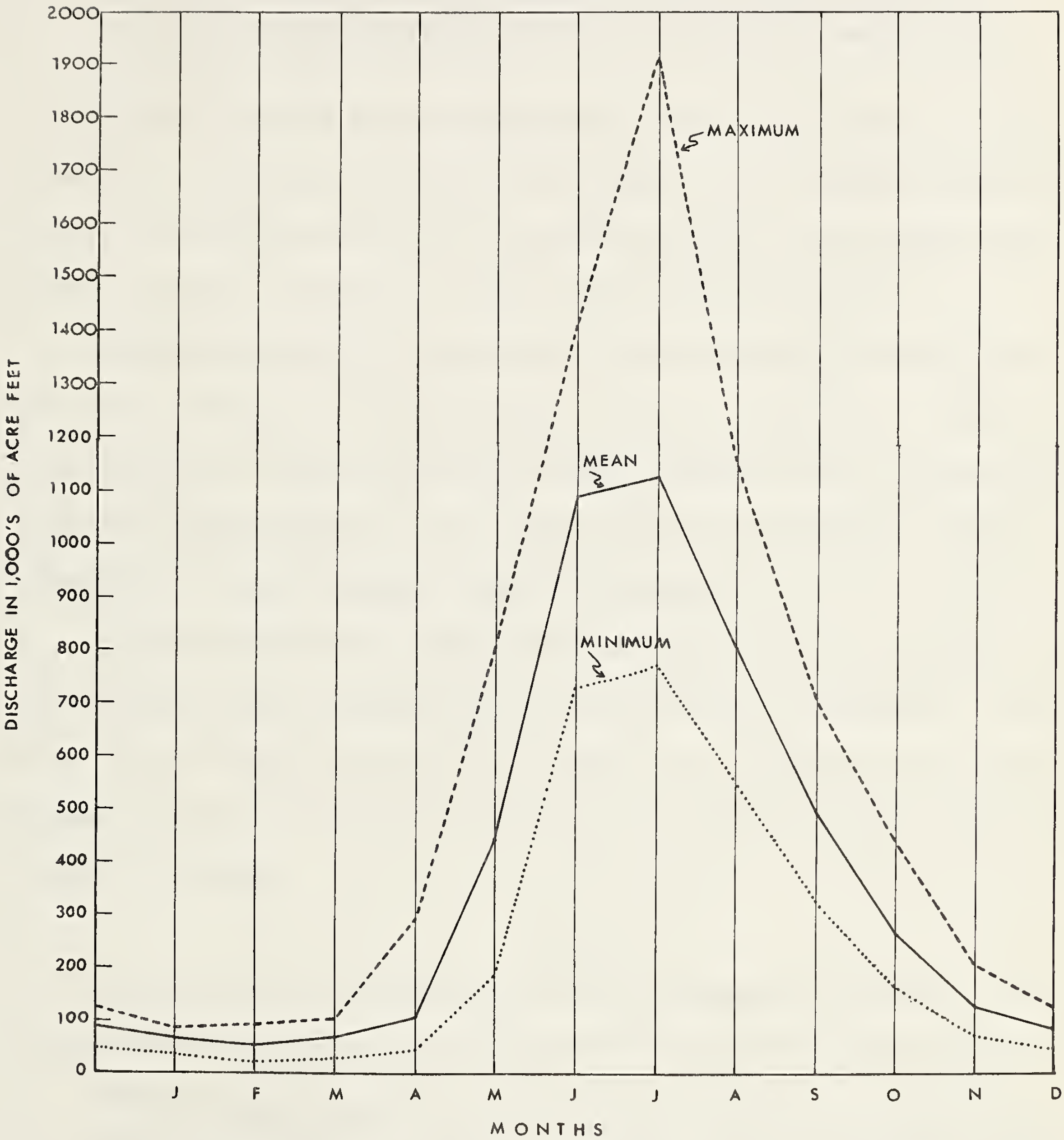
[7] Streamflow data for Athabasca River at Entrance available from: Canada, Dept. of Northern Affairs and National Resources, Water Resources Branch, Water Resources Papers, Arctic and Western Hudson Bay Drainage, Ottawa, 1915-1939, 1955-1961.

[8] J.S. Rowe, Forest Regions of Canada, Canada, Dept. of Northern Affairs and National Resources, Forestry Branch, Bulletin 123, Ottawa, 1959.

[9] E.H. Moss, "The Vegetation of Alberta," Botanical Review, Vol. 21, No. 9, Nov. 1955.

Monthly Discharge For The Athabasca River Near Entrance

(PERIOD OF RECORD: 1919–1939 and 1955–1961)



Source: Canada, Dept. of Northern Affairs and Natural Resources, Water Resources Papers.

FIGURE 8.

Foothills Section of the Boreal Forest Region appears to fit that of the study-area's vegetation:

> The distinctive tree species of the Lower Foothills Section is the lodgepole pine (Pinus contorta var. latifolia) which, with aspen (Populus tremuloides) and balsam poplar (Populus balsamifera) has assumed a dominant position over much of the area in the wake of fire.[10]

White spruce (Picea glauca) and frequently black spruce (Picea mariana) are important constituents in older forest stands. Other species having scattered representation within the study-area are white birch (Betula papyrifera), tamarack (Larix laricina) and Alpine fir (Abies lasiocarpa).

Savage has produced a preliminary vegetation map of Alberta on the scale 16 miles to the inch.[11] On this map, a tongue of vegetation, termed Aspen Poplar Ecotone to Spruce (White and Black), extends up the Athabasca Valley to as far as Brûlé Lake. On the higher slopes of the Athabasca Valley the vegetation is termed Lodgepole Pine-White Spruce.

Although the climax vegetation of the study-area is complex, a succession from lodgepole pine and aspen poplar to white spruce is evident.[12] However, since forest stands of more than 150 years are not common in the study-area (because of repeated fires), the matter of succession and climax are only of academic interest.

SOILS

The soils of the study-area have not been mapped in detail. An ex-

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[10] Rowe, <u>op.cit</u>., p. 25.

[11] M. Savage, MS., Map of Vegetation of Alberta, for proposed Atlas of Alberta, 1965.

[12] Moss, "Forest Communities in Northwestern Alberta," <u>Canadian Journal of Botany</u>, Vol. 31, 1953, p. 235.

ploratory soil survey,[13] carried out in 1955, examined the soils at a few sites and podzolic, brunizolic, and gleyzolic soil orders along with azonal organic soils were found to be represented.[14] (See Table VI, Appendix A for classification and description of soil orders, groups and sub-groups known to occur in the study-area).

The thin capping of silts and sands over the glacio-fluvial terraces has permitted forest growth and the development of zonal soils. However, the large stone content and poor fertility of these soils are serious handicaps for agricultural development. The more fertile till soils along the higher slopes of the Athabasca Valley are also of doubtful agricultural potential and would be better left under forest cover.

The clear-cutting practice of the Hinton pulpwood operation on the forested slopes of the study-area has not greatly affected the soils. Scarification of the soils after clear-cutting has prevented erosion damage and the mixing of organic and upper mineral horizons has improved moisture conditions for the succeeding forest crops.

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[13] J. D. Lindsay, A. Wynnyk, and W. Odynsky, Exploratory Soil Survey of Alberta Map Sheets 83-L, 83-K, 83-F, and 83-J, Research Council of Alberta, Preliminary Soil Report 64-2, Edmonton, 1964.

[14] The soil classification scheme used here is one adopted by the National Soil Survey Committee of Canada in 1960. See "Report of the Meeting of the National Soil Survey of Canada," February 22 to 27, 1960, Ontario Agricultural College, Guelph, Ontario.

CHAPTER III

SURFICIAL DEPOSITS AND BRIEF GLACIAL HISTORY OF THE STUDY-AREA

PLEISTOCENE AND RECENT DEPOSITS[1]

Surficial deposits cover all of the study-area except small areas of exposed bedrock. The majority of the surficial deposits are of Pleistocene origin. The Pleistocene and Recent deposits shown in Figure 9 have been subdivided on the basis of the formative processes and environment, as interpreted from the structure and texture of the deposits and their topographic form. They are discussed below.

Pleistocene Deposits

a. Deposits of Glacial Origin

The most common material of glacial origin is till, which is defined as material deposited directly from the glacier. Till is typically a non-sorted and non-stratified sediment.

The tills of the study-area vary considerably in texture. In some exposures they are silty and clayey and have a stone content (size > 2 mm.) of 20 per cent. In other exposures, however, stones make up more than 50 per cent of the till. As with texture, the colour of the tills varies appreciably, ranging from medium brown to dark gray on fresh unoxidized surfaces.

The coarser particles of the tills are derived from the Rocky Mountains and local bedrock and consist chiefly of limestone, quartzite, conglomeratic

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[1] The surficial deposits of the study-area have been mapped by M.A. Roed, Ph.D. thesis in preparation, Dept. of Geology, University of Alberta, Edmonton, 1966.

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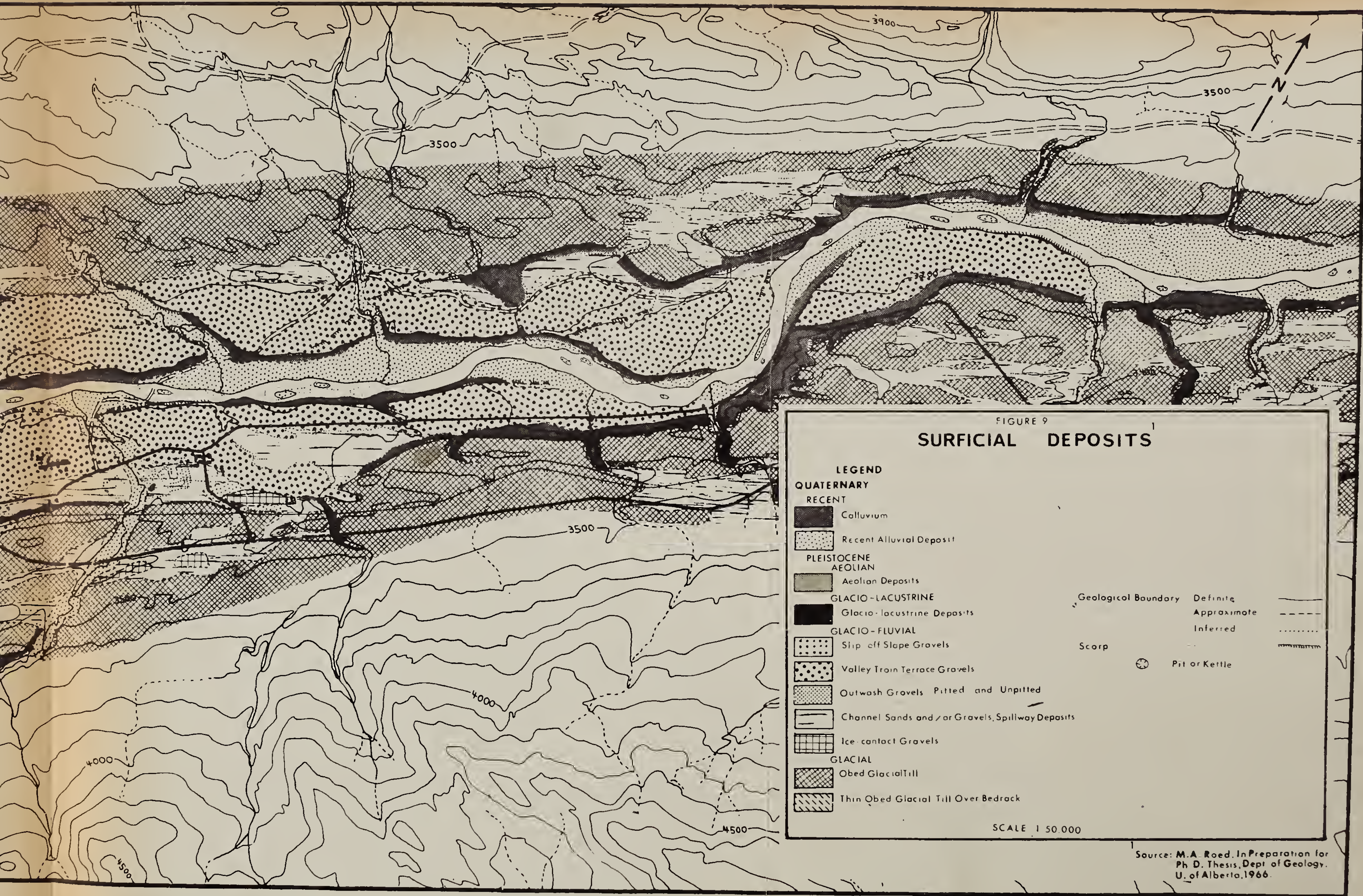
FIGURE 9
SURFICIAL DEPOSITS[1]
LEGEND
QUATERNARY
RECENT
Colluvium
Recent Alluvial Deposit
PLEISTOCENE
AEOLIAN
Aeolian Deposits
GLACIO-LACUSTRINE
Glacio-lacustrine Deposits
GLACIO-FLUVIAL
Slip off Slope Gravels
Valley Train Terrace Gravels
Outwash Gravels Pitted and Unpitted
Channel Sands and / or Gravels, Spillway Deposits
Ice-contact Gravels
GLACIAL
Obed Glacial Till
Thin Obed Glacial Till Over Bedrock
Geological Boundary Definite
Approximate
Inferred
Scarp
Pit or Kettle
SCALE 1 50.000
[1] Source: M.A. Roed, In Preparation for Ph D. Thesis, Dept of Geology, U. of Alberta, 1966.
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quartzite, sandstone and siltstone.

Two till sheets can be recognized in the study-area, but since the subject of this thesis involves the youngest till, only it will be discussed. The youngest till of the study-area was deposited by the Obed Glacier, an expanded toe-valley glacier that extended down the Athabasca Valley at least as far as Obed. On the upper slopes of the Athabasca Valley this till forms a thin blanket and has an undulating topographic expression which is a reflection of the near-surface bedrock. Within the lower parts of the Athabasca Valley, where the Obed till is somewhat thicker, it has been greatly modified by meltwaters from the retreating Obed Glacier. In places Obed till has been left as erosional remnants surrounded by glacio-fluvial outwash (see Figure 9). In other locations little or no glacio-fluvial material has been deposited, although the till has been locally scoured and terraced by glacial meltwaters (see Plate 5).

b. Glacio-fluvial Deposits

Glacio-fluvial deposits are deposits of stratified drift which were deposited by streams derived from the melting of a glacier. Glacio-fluvial deposits fall into two classes:

(1) Ice-contact glacio-fluvial deposits that are formed in contact with glacier ice, and include deposits such as kames, kame terraces, eskers, and pitted outwash.

(2) Proglacial glacio-fluvial deposits that are formed beyond the margins of the glacier and include outwash, valley train and spillway deposits.

Ice-contact Glacio-fluvial Deposits. Ice-contact glacio-fluvial deposits are poorly represented in the study-area. Small isolated deposits occur southeast of Hinton, but the largest deposits are found in conjunction with an end moraine complex near Entrance. Pitted outwash and eskers, two

kinds of ice-contact glacio-fluvial deposits, are recognizable features of the end moraine complex. Across the river from Entrance, specific kinds of ice-contact glacio-fluvial deposits are unrecognizable and have been mapped simply as ice-contact glacio-fluvial deposits.

i) Esker - Only one esker was found in the study-area. This small esker is located about 1 1/2 miles northeast of Entrance (LSD. 5, Sec. 8, Tp. 51, R. 25, W5th Mer.). It is believed to have formed in a tunnel at the base of the Obed Glacier and is part of the end moraine complex formed by the glacier when it maintained a still-stand in the area.

ii) Pitted Outwash - Pitted outwash is considered an ice-contact glacio-fluvial deposit because the pits, or kettles, that form the characteristic pitted surface are created by the melting-out of buried or partly buried blocks of ice. The best example of pitted outwash in the area occurs west of Maskuta Creek Canyon at an elevation of about 3,360 feet (see Figure 9 at LSD. 3, Sec. 5, Tp. 51, R. 25, W5th Mer.). This pitted outwash is part of the same end moraine complex as previously mentioned. The small, shallow pits marking the nearly level pitted outwash surface suggests that the ice masses that formed the kettles were small and/or were deeply covered by outwash material.[2]

Proglacial Glacio-fluvial Deposits. Horizontally bedded outwash gravels covered by Obed glacial till are found along road-cuts near Pedley (see Plate 1 and Figure 10). These proglacial glacio-fluvial sediments form part of a group of sediments referred to as pre-Obed outwash.[3]

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[2] F. T. Thwaites, Outline of Glacial Geology, published privately by the author, Madison, Wisconsin, 1963, p. 47.

[3] M. A. Roed, Ph.D. thesis in preparation, Dept. of Geology, University of Alberta, Edmonton, 1966.

Plate 1. Obed glacial till overlying outwash of the pre-Obed sediments near Pedley.

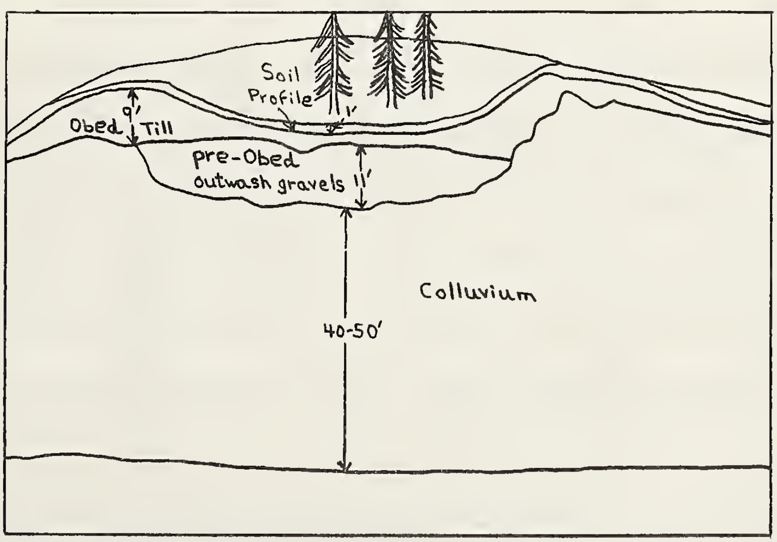

Figure 10. Diagram accentuating the stratigraphic features in the above photograph.

i) Valley Trains - A valley train "is a long, narrow body of outwash confined within a valley."[4] During the retreat of the Obed Glacier two valley trains were deposited in the Athabasca Valley. Remnants of these valley trains are present as paired terraces within the study-area. The description and origin of these terraces is the major theme of this thesis and will be discussed in Chapter IV.

ii) Spillway and Channel Deposits - "Spillways are valleys which were cut by glacial meltwaters issuing directly from the ice or from glacial lakes."[5] A remnant of a well-developed spillway channel occurs on the ridge directly north of Entrance at an elevation of about 3,360 feet (see Figure 2 at LSD. 9, 10, 13 and 14, Sec. 2, Tp. 51, R. 26, W5th Mer.). The spillway remnant is deeply incised into till deposits and has a flat floor approximately 1/8 mile wide. The north bank of the spillway is steep and more than 150 feet high. The south bank is gently sloping and resembles a slip-off slope (see Plate 6). The spillway is floored by over 30 feet of horizontally bedded pebble gravel (see Plate 2). The gravels are overlain by a thin layer of aeolian silts and sands, which in turn are often overlain by recent swamp deposits.

Many small channels have been incised into the till-covered slopes of the Athabasca Valley. These channels, many of which parallel the Athabasca Valley, are actually minor spillways. The channel bottoms are covered by thin veneers of sand and/or gravels. Near Pedley, the channels are incised in Obed till, and having been covered by recent swamp deposits, are easily recognized

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[4] R.F. Flint, Glacial and Pleistocene Geology, John Wiley and Sons, Inc., New York, 1957, p. 139.

[5] C.P. Gravenor, Air Photographs of the Plains Region of Alberta, Research Council of Alberta, Preliminary Report 56-5, Edmonton, Alberta, 1956, p. 8.

Plate 2. View of 30 feet of spillway gravels overlying Obed Till at locality no.65.

Plate 3. View eastward of recent landslide along the lower valley train terrace on the south side of the Athabasca River about 1 mile north of Hinton Valley Town.

on aerial photographs by their dark gray, even tones. Channel deposits of sand are also found occupying abandoned channels on the valley train terraces.

c. Glacio-lacustrine Deposits

Glacio-lacustrine sediments are rare in the study-area. They outcrop in the lower valley train terrace below the Hinton Pulp Mill, where they underlie glacio-fluvial gravels. The glacio-lacustrine sediments are believed to be part of the pre-Obed sediments and consist of very fine sands, silts and clays. Bedding is visible in some outcrops, and contortion and fracturing of the beds is common. Contortion and fracturing may have resulted from the overriding of the Obed Glacier.

Glacio-lacustrine sediments also occur near the junction of Highway 16 and Maskuta Creek. The sediments were deposited in a small glacial lake that occupied the Maskuta Creek Valley during the time of retreat of the Obed Glacier. The sediments consist of very fine sands, silts, and clays. Although bedding is present it is distinct only on weathered surfaces.

d. Aeolian Deposits

Much of the study-area is covered by thin deposits of silt and fine sand of aeolian origin, derived mainly from the nearby valley train outwash. Small longitudinal and parabolic sand dunes east of Maskuta Creek on the upper valley train terrace show that the wind direction was from the west.

Recent Deposits

a. Recent Alluvial Deposits

Recent alluvial deposits have been mapped as a single unit (see Figure 9) but it is hoped that the distinction between depositional features (alluvial fans, etc.) and erosional features (alluvial terraces, etc.) should be readily apparent.

Alluvial Terraces. At various times during the postglacial period climatic changes have brought about sequences of aggradation and degradation resulting in alluvial terraces being formed along the Athabasca River. Preservation of these terraces in the study-area has been hampered by deposition of colluvium and by the narrowness of the Athabasca Valley between the lower valley train terrace remnants. An alluvial terrace remnant stands approximately 10 feet above the Athabasca River at the mouth of Maskuta Creek (see Figure 19, Plate 7). Below Hinton an island rising 8 feet above river level is believed to be a remnant of an alluvial terrace. Since it is covered by a mature stand of trees it is probably not part of the modern flood plain, except, possibly, in times of exceptional flood. A section through this island shows that the upper four feet consists of fine bedded sand, while the lower four feet consists of pebble to cobble gravel.

Alluvial Fans. Alluvial fans have been produced at the mouths of streams entering the Athabasca River. Erosion of the valley train deposits by these streams has resulted in the alluvial fans being composed mainly of pebble to cobble gravel. Fish Creek and Happy Creek are but two streams in the study-area that have built large alluvial fans.

Athabasca River Alluvium. From the mouth of Maskuta Creek downstream to Trail Creek the modern Athabasca River flows in a straight channel over an undulating bed, regularly interspersed by alternating pools and riffles. This alternation of pools and riffles is characteristic of gravel-bed streams.[6] The Athabasca River is believed to be such a stream because the bars that form the riffles become exposed during times of low flow and are known to consist mainly of pebble to cobble gravel.

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[6] L.B. Leopold, M.G. Wolman and J.P. Miller, Fluvial Processes in Geomorphology, W.H. Freeman and Co., San Francisco, 1964, p. 203.

b. Colluvium and Landslide

Colluvium is a general term for material which has moved downslope under the influence of gravity. Usually the composition of colluvium is heterogeneous and in places often appears similar to the tills in the study-area. Colluvium veneers most of the slopes in the study-area regardless of the underlying material. It also masks the scarp faces of the valley train terraces, permitting few exposures of the underlying material.

A recent landslide is present along the lower valley train terrace below Hinton (LSD. 12, Sec. 30, Tp. 51, R. 25, see Plate 3).

BRIEF GLACIAL HISTORY OF THE STUDY-AREA

Two advances of Cordilleran ice within the study-area are represented by two distinct till sheets. The till sheets can be separated on the basis of composition, stratigraphy and geomorphology.

The oldest Cordilleran glacier was a piedmont glacier that extended far down the Athabasca River to the northeast, covering the divide areas northwest and southeast of the study-area.[7] This glacier met with the Continental Ice Sheet to the east and northeast and was deflected southeastwards to flow between the Continental Ice Sheet and the mountainous terrain to the west. Erratics carried by the piedmont ice from the Athabasca Valley may have resulted in formation of the Foothills' Erratics Train.[8, 9]

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[7] Pers. comm. M.A. Roed, Dept. of Geology, University of Alberta, Edmonton, 1966.

[8] E.W. Mountjoy, "Jasper Area, Alberta, A Source of the Foothills Erratics Train," Alberta Society of Petroleum Geologists, No. 6, 1958, pp. 218-226.

[9] M.A. Roed, E.W. Mountjoy and N. Rutter, in preparation, The Athabasca Valley Erratics Train, 1966.

The terminus of the piedmont glacier retreated to at least the Front Ranges of the Rocky Mountains. Ice-contact and proglacial glacio-fluvial sediments and lacustrine sediments were deposited in the Athabasca Valley during the withdrawal of the glacier. These sediments, termed pre-Obed sediments, are overlain by younger glacial deposits, mainly Obed till forming most of the surface deposits below 4,200 feet elevation in the area.

The last glacier to enter the study-area was the Obed Glacier, an expanded toe-valley glacier, that almost filled the broad Athabasca Valley to as far east as Obed.

The front of the Obed Glacier steadily retreated up the Athabasca Valley, depositing glacio-fluvial sediments. A still-stand near Entrance resulted in deposition of the upper valley train. A further retreat and still-stand, upstream of the study-area, resulted in dissection of the upper valley train and deposition of the lower valley train, respectively. The deposition and terracing of these valley trains is the major theme of this thesis and will be discussed in Chapter IV.

CHAPTER IV

DESCRIPTION AND ORIGIN OF THE VALLEY TRAIN TERRACES

GENERAL STATEMENT

Paired terraces representing remnants of two Pleistocene valley trains were found within the study-area. Valley train formation and terracing occurred during the retreat of the Cordilleran Obed Glacier, an expanded toe-valley glacier, that was the last to occupy the area. The older and higher valley train, called the upper valley train, is related to an end moraine present within the study-area. The younger valley train, called the lower valley train, was deposited by the Obed Glacier when it maintained an undetermined position upstream of the study-area.

CHARACTERISTICS OF VALLEY TRAINS

A few of the characteristic features of Recent and Pleistocene valley trains are listed below. A number of these features characterize the study-area's terraces and justify their identification as valley train remnants.

<u>Characteristic Features of Valley Trains</u>:

(1) A long, narrow body of outwash confined within a valley;

(2) Gradients of 0.5 to 1% in the headward parts, with exceptional gradients as steep as 7% having been recorded;

(3) Active valley trains reach their greatest height along their longitudinal axes and slope slightly towards the lateral margins;

(4) The headward parts of valley trains are often pitted with kettles, resulting from the melting out of ice blocks;

(5) Valley trains can often be traced and related to end moraines; and

(6) Valley trains are usually cut into paired terraces by glacial melt-waters following the formation of the valley trains.

UPPER VALLEY TRAIN TERRACE

Extent of Upper Valley Train Terrace

The upper valley train terrace level is represented by two large remnants. The larger of the two covers an area of about 4 square miles on the north side of the Athabasca River (see Figure 11). The other remnant, located across the river, extends 3 1/2 miles downstream from Maskuta Creek. The older part of Hinton (Hinton Hill Town[1] in Figure 11) is located on the downstream end of this remnant.

Geomorphology

Altimeter readings taken on the south side of the Athabasca River show that the upper valley train terrace decreases in elevation downstream, having a gradient of about 7 feet per mile and an average elevation of 3,330 feet, about 190 feet above the Athabasca River. The remnant across the river has a similar gradient and average elevation, except near its upstream end, where the gradient steepens to over 35 feet per mile and elevations of 3,410 feet occur. This steepening of the valley train at the margin of the glacier is common and is another characteristic of valley trains.[2] The contact between the upper and lower valley train surfaces on the north side of the

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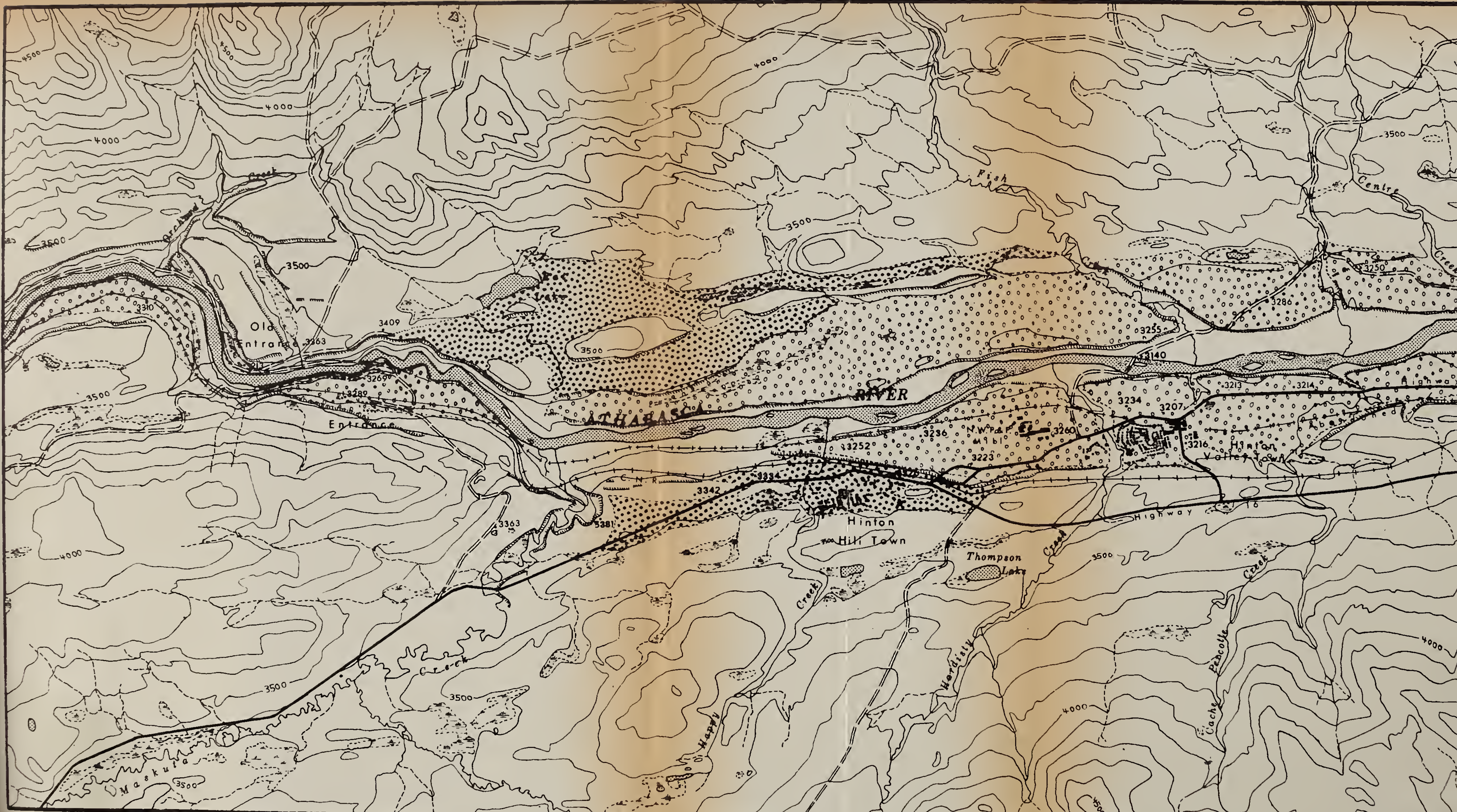
[1] The town of Hinton is divided into two parts, one of which is located on an upper valley train remnant and the other on a lower valley train remnant. For ease of locating glacial features the parts of Hinton have been given different names in this thesis. That part of Hinton located on the upper valley train terrace is termed Hinton Hill Town, while the part of town on the lower valley train terrace is termed Hinton Valley Town.

[2] L.B. Leopold, M.G. Wolman and J.P. Miller, Fluvial Processes in Geomorphology, W.H. Freeman and Co., San Francisco, 1964, p. 475.



4500
4000
3500
Fish
Centre
Creek
Orchard
Old
Entrance
3409
3363
3310
3269
3289
Entrance
ATHABASCA
RIVER
3252
3236
3223
3234
3207
3213
3214
3216
3255
3250
3286
3260
C.N.R.
3342
3334
3381
3363
Hinton
Hill Town
Hinton
Valley Town
Highway
Thompson
Lake
Creek
Happy
Hardisty
Cache
Percotte
Creek
Maskuta

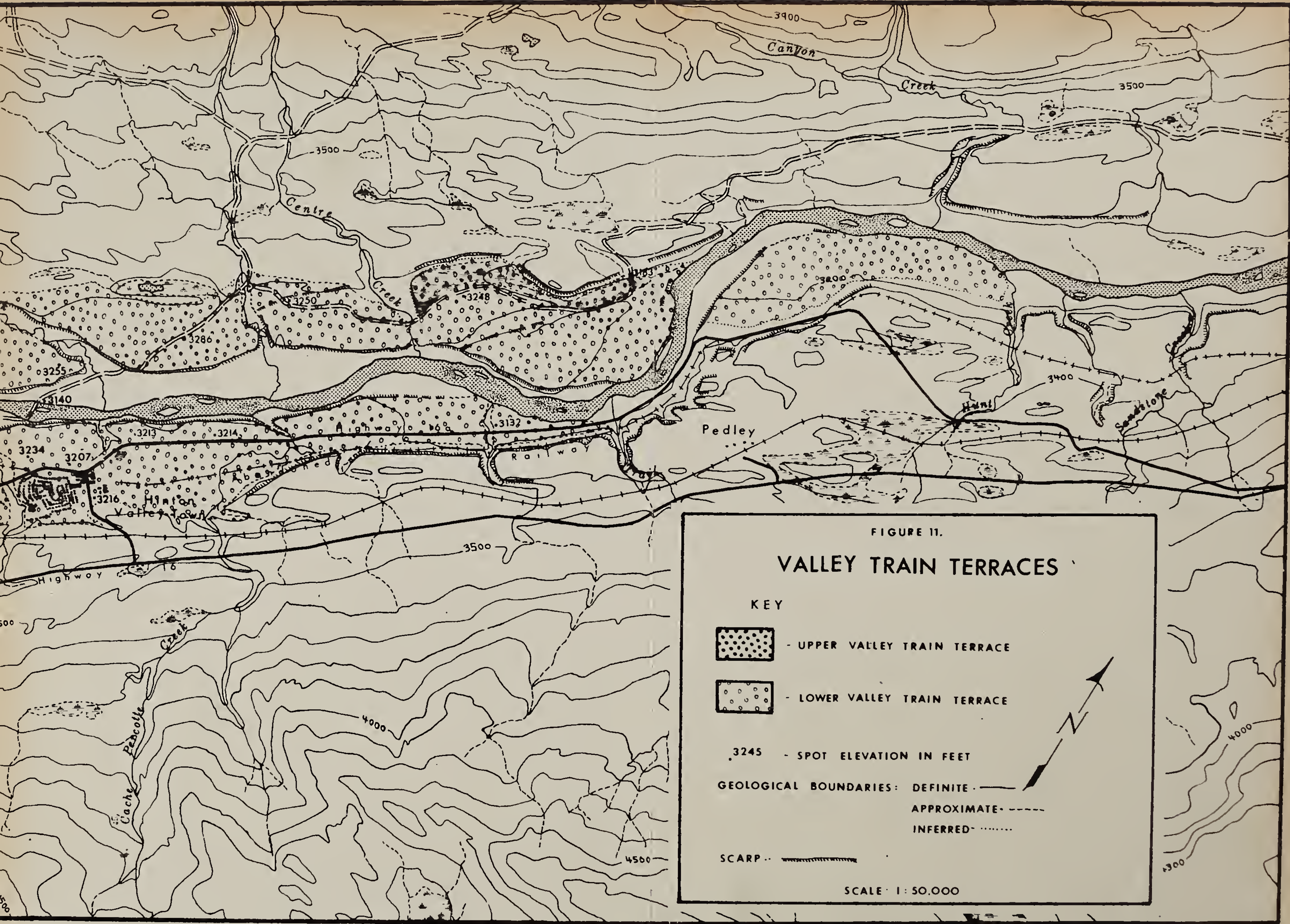


FIGURE 11.

VALLEY TRAIN TERRACES

Athabasca River changes downstream from a steep scarp face to a relatively gentle slope (see Figure 11). On the south side of the river the two valley train terraces are separated by a steep scarp face.

Cross-sections of the upper and lower valley train terraces are shown in Figures 12, 13 and 21. Figure 14 shows the locations of the cross-sections. They provide a general idea of the stratigraphic relations of the surficial deposits. The thicknesses of the surficial deposits in most portions of the cross-sections are only estimates. Although the cross-sections have a vertical exaggeration of 5.2, their topographic profiles appear natural, since the human eye exaggerates the height of topographic features and the steepness of slopes when seen from ground level.[3]

The cross-sections show that the upper valley train terrace remnants do not slope toward the valley margins as is characteristic of active valley trains. Instead they display no perceptible cross-valley slope.

The surface of the upper terrace is irregular and a relief of 30 feet occurring within a short distance is not uncommon. The local relief is due to the preservation of the valley train surface, with its many channels and gravel bars. Some of the channels of the valley train terraces are indicated in Figure 15. Recent slope wash and a thin mantle of wind-blown silt and sand have done little to modify the valley train terrace surfaces.

A number of till "islands" project high above the surface of the upper valley train terrace (see Figure 12). The "islands" are remnants of Obed till that escaped erosion during the time of formation of the upper valley train. On the north side of the Athabasca River, a long row of till "islands" parallel and divide the upper valley train terrace. Some "islands" rise as much as 150 feet above the terrace surface.

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[3] A.N. Strahler, Introduction to Physical Geography, John Wiley and Sons, Inc., New York, 1965, p. 427.

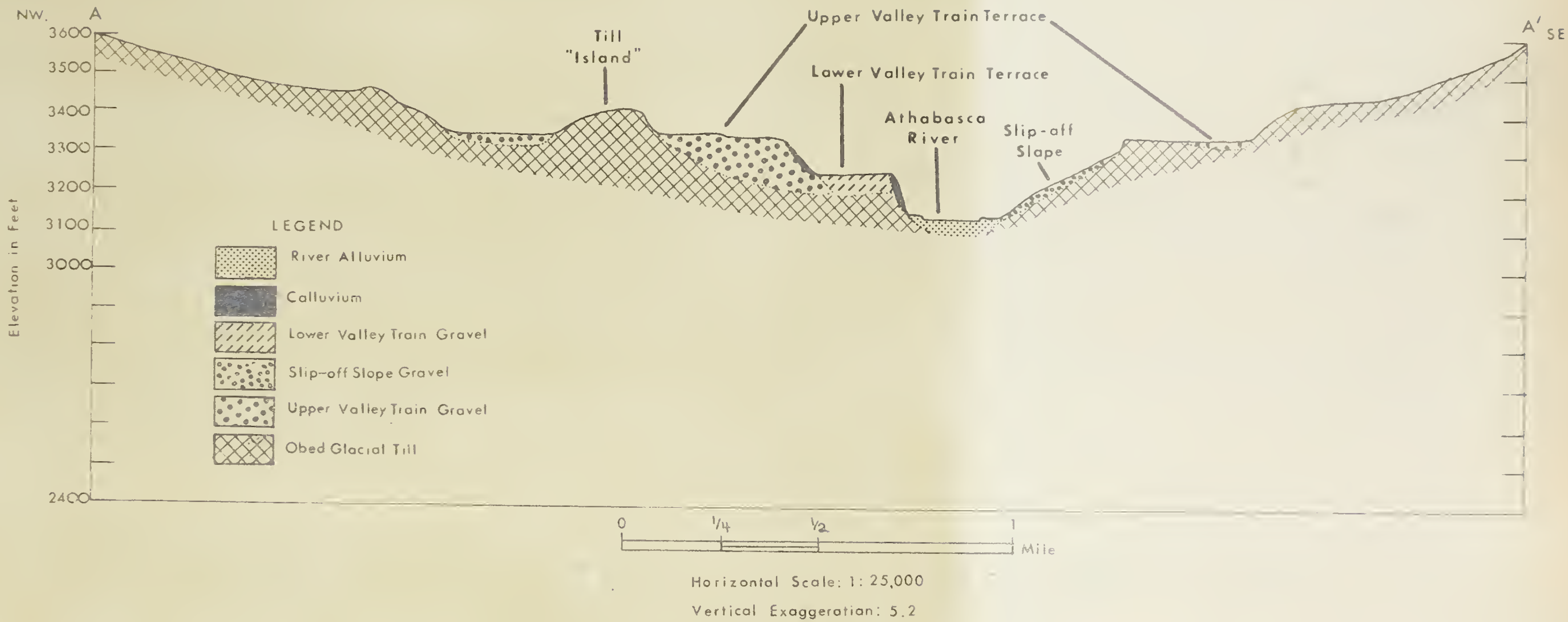

Figure 12 - Cross-section of the Athabasca Valley one-half mile west of Hinton Hill Town showing generalized stratigraphic relationships and terrace outlines.

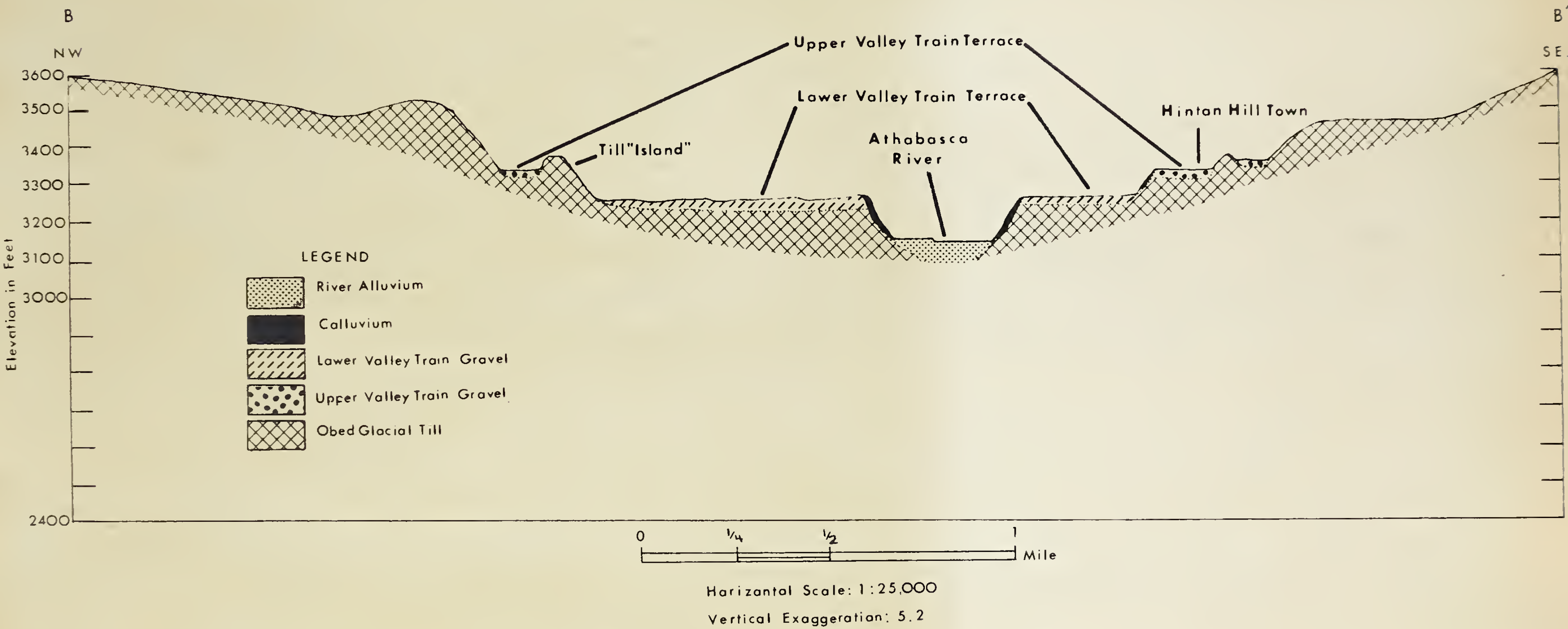

Figure 13 - Cross-section of the Athabasca Valley at Hinton Hill Town showing generalized stratigraphic relationships and terrace outlines.

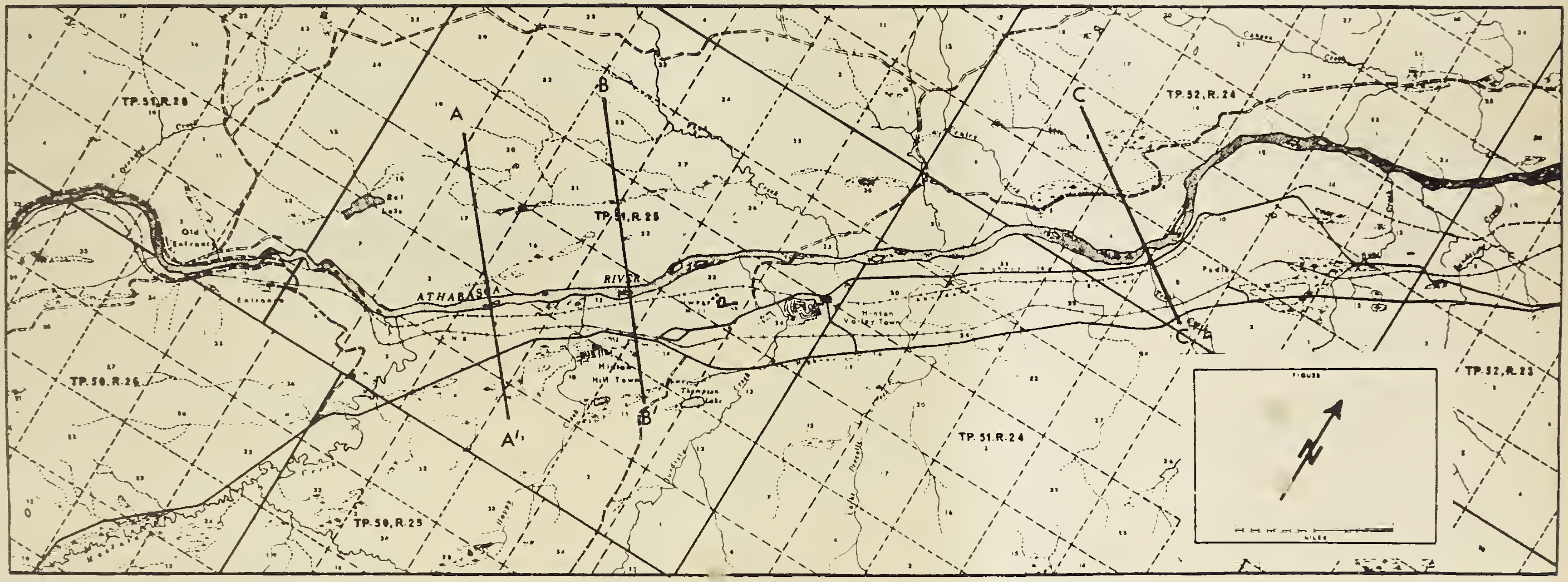

Figure 14 - Location of cross-sections shown in Figures 12, 13, and 21.

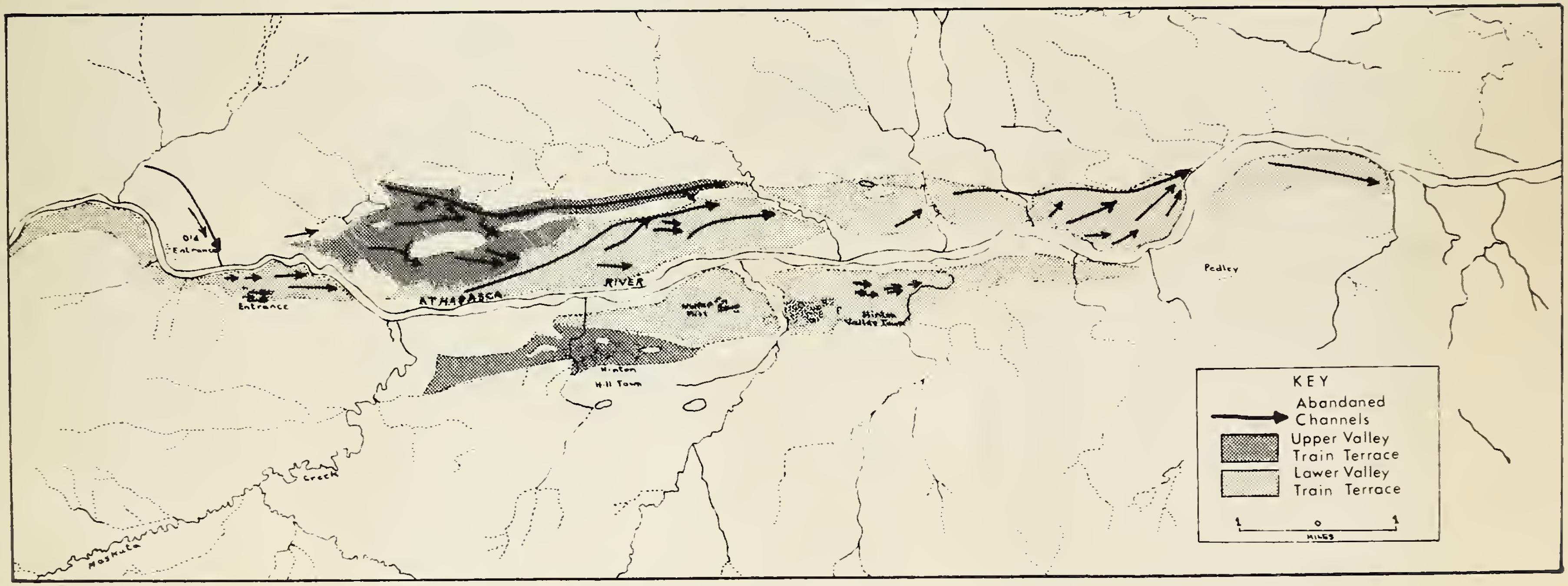

Figure 15. — Abandoned Channels an the Upper and Lawer Valley Train Terraces.

Stratigraphic Units

Good exposures of the materials comprising the upper valley train terrace are rare. A gravel pit near Hinton Hill Town provides an exposure which is the type locality for the upper terrace materials (locality 52b in Figure 23 in Appendix B). Plate 4 and Figure 16 show a photograph and illustration, respectively, of this type locality. Details of the materials in this exposure are given in the following stratigraphic section:

TABLE II - STRATIGRAPHIC SECTION OF UPPER VALLEY TRAIN TERRACE ON WALL OF GRAVEL PIT BETWEEN HINTON HILL TOWN AND THE ATHABASCA RIVER

	Lithologic Description	Thickness in feet
unit A :	Gravel, horizontally bedded with individual beds being indistinct. Gravel is subrounded, ranging up to 2 feet in diameter. Median gravel size is 1 1/4 inches. Boulders over one foot comprise 5 to 10% of unit. The matrix of sand and silt comprises only 10 to 15% of the unit. Some of the gravel is heavily coated with calcium carbonate. Unit A is separated from the underlying unit B by a thin, horizontal bed (6-10 inches thick) of fine to medium grained sand.	3
unit B :	Gravel, cross-bedded, individual beds are short and discontinuous. Most cross-bedding dips downstream at angles of 20° to 25°. The individual beds of the cross-bedding vary in thickness from 1 to 18 inches and a few are composed mainly of sand. The gravels are subangular to subrounded and boulders over one foot in diameter make up only 1 to 2% of the unit. Unit B is more heterogeneous than unit A, with large boulders often occurring in finer grained strata. The matrix of sand and silt comprises 10 to 20% of the unit.	12
Colluvium :		

From examination of the few exposures along the upper valley train terrace it was found that unit A varied in thickness from less than one foot to more than five feet. The exposures also showed that the contact between units A and B was generally sharp and horizontal. The thin sand bed separating units A and B at the type locality of the upper valley train

Plate 4. Upper valley train gravels exposed at their type locality in a gravel pit near Hinton Hill Town. View eastward at locality no. 52 b.

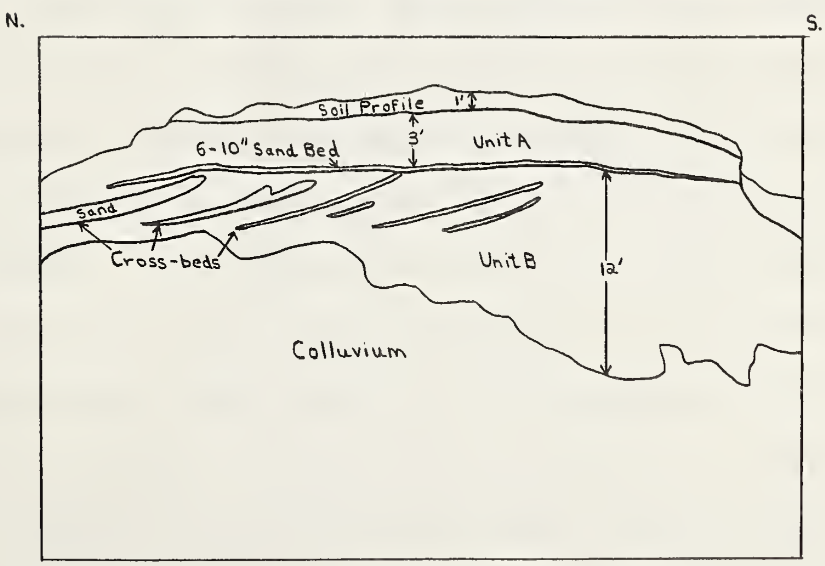

Figure 16. Diagram accentuating the stratigraphic features in the photograph above.

gravels proved, however, to be atypical.

There was also much variation in the unit B gravels along the upper valley train terrace. Such variation occurred in: (1) the amount and thickness of cross-bedding; (2) the amount of calcium carbonate coating on the gravel; and (3) in the sorting and roundness of the gravels.

Physical Properties of the Terrace Gravels

Suites of 100 pebbles each were collected from the stratigraphic units of the upper and lower valley train terraces. An attempt was made to distinguish the gravels of the two valley terraces on the basis of lithologic composition. Median size pebbles analyzed were in the 1 to 1 1/2 inch range and were subangular to subrounded (see Figure 17). No attempt was made to study the change in median size, roundness or sphericity of the terrace gravels with distance of transportation and the effect of the pebbles on these values.

Table III shows the pebble analyses of gravel samples from the upper and lower valley train terraces. The percentage of each pebble type varied considerably from one sample point to another in both terraces.[4] Quartzite and conglomeratic quartzite pebbles derived mainly from the Main Ranges of the Rocky Mountains, are the most abundant type in the upper valley train terrace gravels. Their resistance to glacial and glacio-fluvial abrasion is much greater than that of the less abundant and less resistant limestone and dolomite pebbles, whose source in the Front Ranges is much closer. The local bedrock of shale, siltstone and sandstone provides only a low percentage of pebbles in the gravels of the upper and lower valley train

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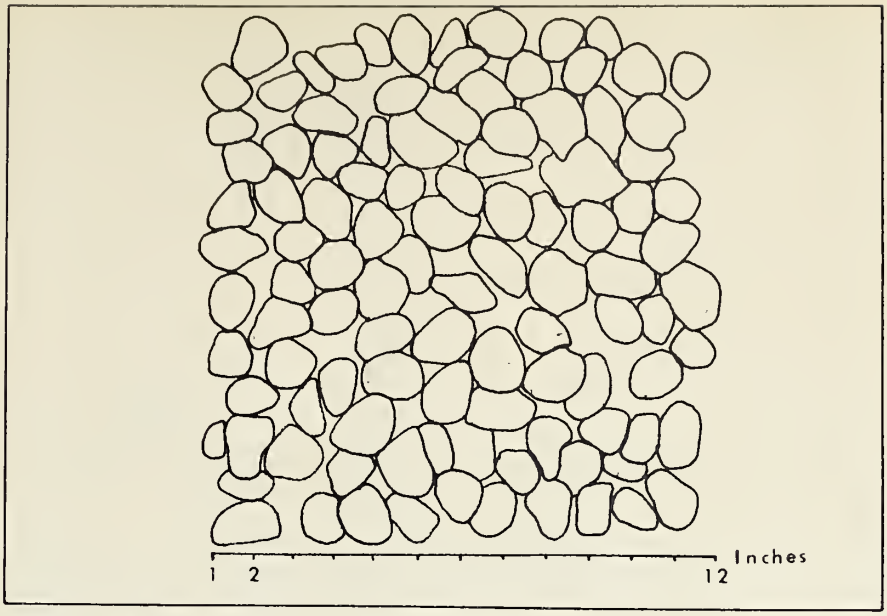
[4]The gravel samples taken from the two valley trains will be compared in the following discussion on the lower valley train terrace in the section on stratigraphic units.

(A)



(B)

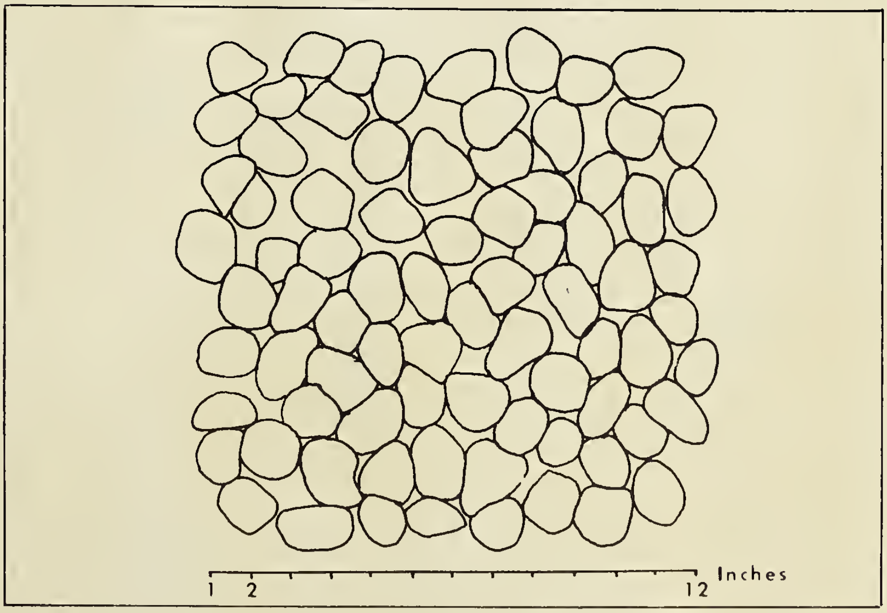


Figure 17. - Drawings Showing: (A), The Subrounded to Subangular Nature of Unit B Gravel, and (B), The Subrounded Nature of Unit A Gravel. Pebble Outlines Taken From Photographs.

TABLE III - PEBBLE ANALYSES OF GRAVEL SAMPLES FROM THE UPPER AND LOWER VALLEY TRAIN TERRACES

	Sample No.	Locality	Strati-graphic unit	Pebble Type (in per cent)					
				Quartzite	Limestone	Dolomite	Sandstone	Siltstone	Others[1]
Upper Valley Train Terrace:									
	52b	LSD14,Sec.10,Tp.51,R.25	A	54.6	27.8	9.3	7.4	1	nil
	52b	LSD14,Sec.10,Tp.51,R.25	B	41.5	34.8	16.1	6.8	1	nil
	52a	LSD14,Sec.10,Tp.51,R.25	A	54	20	10	15	1	nil
	171	LSD1,Sec.15,Tp.51,R.25	B	44.7	20.4	17.5	0	17.5	nil
	64	LSD2,Sec.12,Tp.51,R.26	B	48.5	38	9.7	7.8	1	nil
	Average			48.7	28.2	12.5	7.4	4.3	nil
Lower Valley Train Terrace:									
	50a	LSD4,Sec.25,Tp.51,R.25	a	37.5	38.5	9.6	9.6	2	1
	50a	LSD4,Sec.25,Tp.51,R.25	b	38.8	34.2	21.9	7	nil	nil
	54	LSD3,Sec.23,Tp.51,R.25	b	42.1	28.4	15.8	1.1	10.5	2.1
	55	LSD6,Sec.15,Tp.51,R.26	b	38.1	39.1	7.6	6.7	9.5	2
	122	LSD12,Sec.6,Tp.51,R.26	a	50.5	25.8	6.2	11.3	2.1	4.1
	59	LSD13,Sec.34,Tp.50,R.26	b	23.8	51.5	10.9	8.9	2	3
	66	LSD7,Sec.3,Tp.51,R.26	b	31.6	47.4	9.5	4.3	7.4	nil
	Average			37.5	37.8	11.6	7.0	4.8	1.7

[1]Others include argillite, arkose, mica quartz schist, phosphate, chert pebbles.

terraces. This is to be expected because such bedrock would probably disintegrate rapidly when subjected to stream abrasion.

Origin

The Cordilleran Obed Glacier, an expanded toe-valley glacier, was the last to occupy the study-area. The position of the Continental Ice Sheet at the time of the advance and retreat of the Obed Glacier has not been determined. The Continental ice did not, however, act as a dam, ponding the Obed Glacier's meltwaters within the Athabasca Valley of the study-area. The extensive glacio-fluvial sediments in the study-area attest to the fact that meltwater drainage from the retreating Obed Glacier proceeded without obstruction downstream along the Athabasca Valley.

The main method of retreat of the Obed Glacier was probably backwasting. From the glacier's terminal position north of Obed upstream to Entrance, frontal retreat was rapid, as suggested by the fact that no end or recessional moraine deposits were found in this stretch.

A prolonged still-stand of the Obed Glacier near Entrance resulted in the deposition of the upper valley train (see Figure 18). Pitted outwash and kame-like deposits near the head of the valley train suggest that at least part of the glacier's terminus was stagnant (see Figure 18). A stagnant or nearly stagnant Obed Glacier near Entrance would also explain the absence there of ridges of till that are usually found in association with end and recessional moraines.[5]

The unit B gravels of the upper valley train were the first to be deposited. Rapid aggradation of these gravels accounts for their coarse, poorly sorted, subangular to subrounded nature. The short, discontinuous

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[5]F.T. Thwaites, Outline of Glacial Geology, privately published by the author, Madison, Wisconsin, 1963, p. 40.

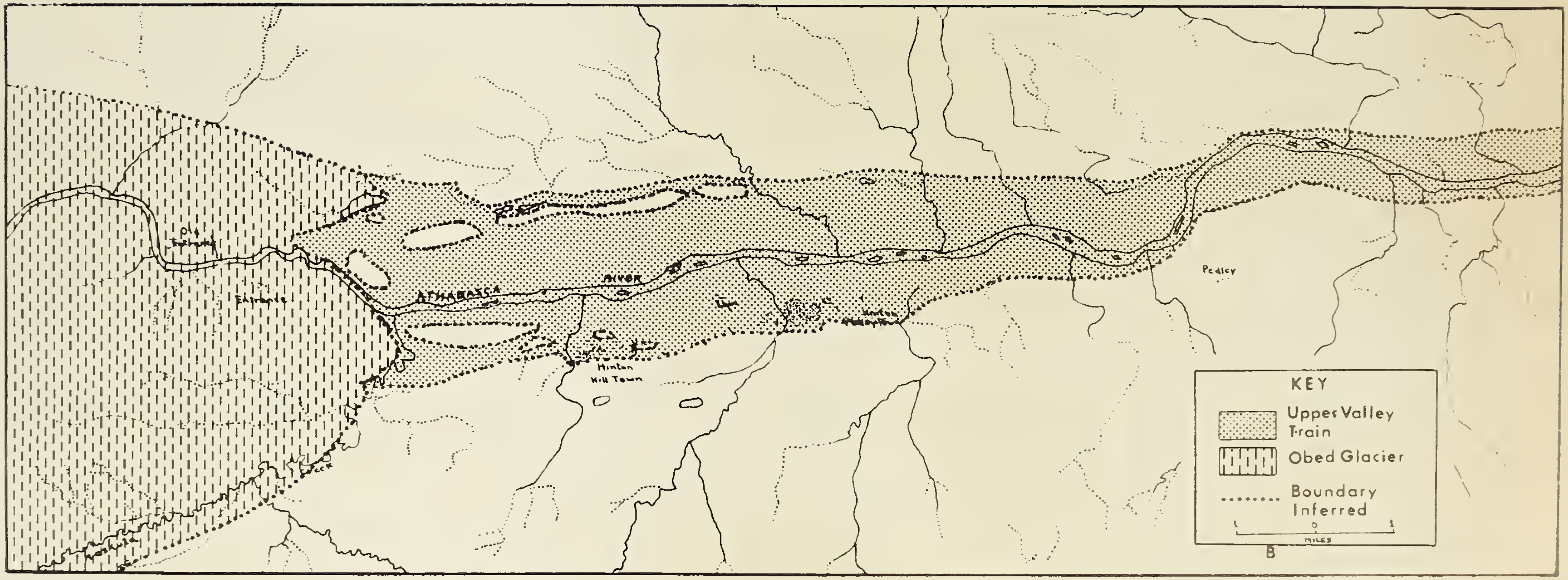

Figure 18 - Map showing probable extent of the Upper Valley Train before terracing occurred.

cross-strata in unit B is typical of outwash.[6] The widely fluctuating glacial meltwaters erode and deposit outwash material, resulting in truncation of most of the cross-strata.

The steepened gradient at the head of the upper valley train is believed to have resulted from the deposition of the coarser part of the glacial meltwater load acquired upstream from the Obed Glacier's terminus.[7] The lack of exposures in this region, however, fails to prove whether the gravels are coarser than those farther downstream. It is probable that the terrace gravels attain their maximum thickness near the head of the upper valley train, although no evidence in the form of exposures and drill records is available to prove this point.

Much of the load carried by the Obed Glacier meltwater streams was eroded from morainic debris and glacio-fluvial sediments in the reach below the glacier. The occurrence of till "islands" above the upper valley train surface proves they are remnants of larger till masses that were eroded by glacial meltwaters to form much of the upper valley train outwash.

Exposures in the upper valley train terrace show a sharp, nearly horizontal contact between unit B and the overlying unit A gravels. The thin layer of unit A gravels is probably channel gravel which resulted from reworking of the uppermost unit B gravels by glacial meltwaters. The planed surface of unit B could have been cut and the unit A gravels deposited in a short time by a degrading stream in "shifting equilibrium,"[8] or by a graded

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[6] R. F. Flint, <u>Glacial and Pleistocene Geology</u>, John Wiley and Sons, Inc., New York, 1957, p. 137.

[7] <u>Loc. cit.</u>

[8] "Shifting equilibrium" is a term devised by Mackin to describe a stream which can adjust to keep pace with gradual changes in the relationship of the hydraulic factors. A stream in "shifting equilibrium" may either deposit part of its load and build up its channel to a steeper gradient, or it may deepen its channel to lower its gradient.

stream over a longer period of time.[9] The former possibility is more likely since it is doubtful that the Obed Glacier maintained a long enough still-stand near Entrance for the meltwater streams to become graded. Unfortunately insufficient exposures exist along the upper valley train terrace to compare the rates of downstream decrease in grain size of the gravels in units A and B. If it could be proven that the rate of downstream decrease in grain size was less rapid for the unit A gravels, it would show that they were deposited by a degrading stream in "shifting equilibrium."[10] Deposits of aggrading streams, such as those that deposited unit B gravels, should show a more rapid downstream decrease.

It is probable that climatic changes resulted in the retreat of the Obed Glacier from its long maintained still-stand near Entrance. The retreat of the glacier provided additional quantities of water which not only partly reworked the upper valley train sediments but produced sufficient flow to erode the valley alluvium.[11] This erosion of the upper valley train created the paired upper valley train terraces of the study-area.

The meltwaters that terraced the upper valley train in most instances probably produced steep scarp faces. However, one locality on the south side of the Athabasca River below Maskuta Creek indicates that the meltwater stream meandered slightly and incision into glacial drift produced a slip-off slope covered by coarse gravels (see Plate 7 and Figure 19).

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[9] A.M. Gooding, "Pleistocene Terraces in the Upper Whitewater Drainage Basin, Southeastern Indiana," Indiana Science Bulletin, No. 2, Richmond, Indiana, 1957, p. 11.

[10] J.H. Mackin, "Concept of the Graded River," Geological Society of America Bulletin, Vol. 59, 1948, p. 477.

[11] Leopold, Wolman and Miller, op.cit., p. 476.

Evidence that the retreating Obed Glacier provided abundant supplies of water occurs on the ridges north and west of Old Entrance. Here, extensive till deposits have been scoured and, in places, terraced by the meltwaters (see Plate 5). The terraced surface lies at an elevation of about 3,400 feet. The existence of a few "island" remnants of till standing above and completely surrounded by the terraced surface is evidence that the terraced surfaces were formed by "scouring." Very little glacio-fluvial material mantles the terraced surface as apparently the additional quantities of water provided by the retreating Obed Glacier were sufficient to transport most of the load downstream.

The terraced till surface was later incised by a spillway carrying meltwaters from the retreating Obed Glacier. A remnant of this spillway occurs at an elevation of approximately 3,360 feet on the ridge north of Old Entrance (see Plate 6). Over thirty feet of horizontally bedded pebble gravel floor the spillway (see Plate 2). It is likely that the spillway channel was incised during an initial stage of high meltwater discharge following which there was aggradation of the gravels.[12]

LOWER VALLEY TRAIN TERRACE

Extent of Lower Valley Train Terrace

Extensive remnants of the lower valley train terrace occur in the area (see Figure 11). Large parallel remnants flank the Athabasca River in the central portion of the area, while to the west smaller isolated remnants occur only along the south side of the river. Downstream near Pedley, the Athabasca River bends northward around the easternmost occurrence of the lower valley train terrace.

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[12] L. A. Bayrock, Glacial Geology Alliance-Brownfield District, Alberta, Research Council of Alberta Preliminary Report 57-2, Edmonton, 1957, p. 20.

Plate 5. View looking westward along terraced till surface on ridge above Old Entrance. The terraced surface lies at an elevation of about 3,400 feet and was cut by meltwaters of the retreating Obed Glacier.

Plate 6. View looking eastward at downstream end of spillway (which eroded upper valley train gravels) at elevation 3,360 feet on ridge above Old Entrance. Photograph was taken from the steep 150-foot high north bank of the spillway. Note the gentle slip-off slope comprising the south bank. Both banks are composed mainly of till.

Geomorphology

Altimeter readings taken on the lower valley train terrace show that the remnants vary in elevation and surface slope. Elevations taken on the terrace remnant, on which Hinton Valley Town is located, range from 3,260 feet near the upstream end to 3,132 feet near the downstream end (see Figure 11). Downstream slopes of the terrace remnant, however, are hard to ascertain because of large local relief. An examination of spot elevations in Figure 11 reveals that a downstream slope does occur, but in places there is more slope toward the river and valley wall than downstream. The middle and upstream reaches of the remnant represent the original lower valley train surface; the downstream slope was found to be about 20 feet per mile. The lower end of the remnant has been partially eroded and as a result, has a steeper gradient of about 50 feet per mile.

Across the river from Hinton Valley Town the lower valley train is well represented. This terrace remnant often exceeds elevations of 3,300 feet near its scarp and has a distinct slope toward the valley side (see Plate 7 and Figure 19). The flat surface of the remnant is visible in Plate 9.

The settlement of Entrance is situated on a remnant of the lower valley train terrace but differs from downstream remnants in being mainly bedrock cored. A number of smaller and discontinuous terraces are present on this part of the terrace, producing a local relief of over 50 feet (see Plate 8 and Figure 20).

Another bedrock cored remnant of the lower valley train terrace is located two miles upstream from Entrance on the south side of the Athabasca River. It lies at an elevation of about 3,300 feet and slopes slightly downstream. There is also a slight cross-valley slope toward the river from the flanking till ridge (see Plate 10).

Plate 7 - View looking east down Athabasca Valley from ridge overlooking Maskuta Creek. Remnants of the valley train terraces can be seen. The lower terrace on the left side of the river slopes towards the valley wall. Maskuta Creek, cuts through an alluvial terrace of the Athabasca River in the right foreground.

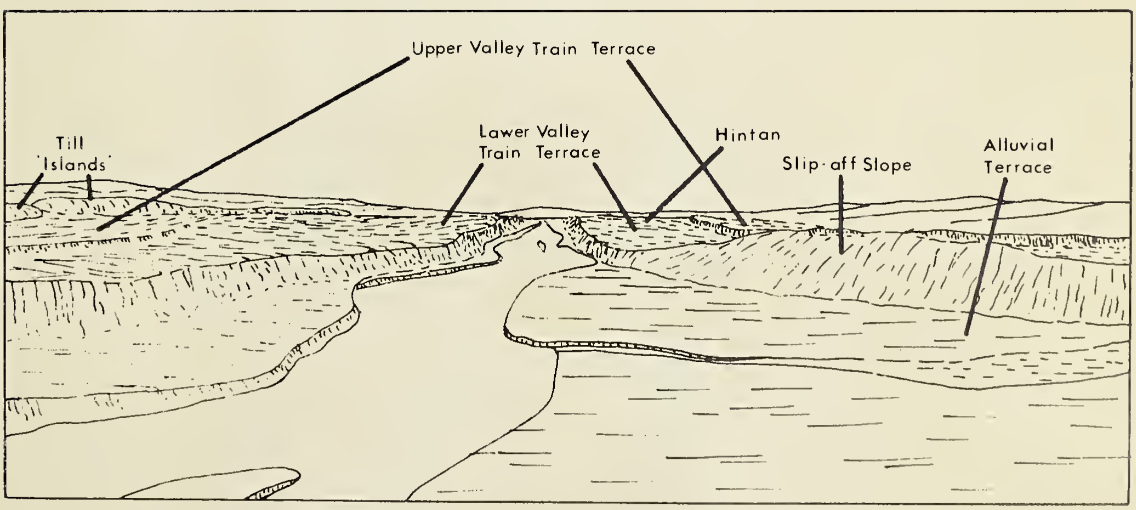

Figure 19. - Sketch accentuating the glacial features in the photograph above.

Plate 8. - View Southword Across the Athobosca River From the Upper Valley Train Terroce to Lower Valley Train Terrace Remnant ot Entrance. The Smoll Scarps on the Remnant Were Corved Out of Bedrock.

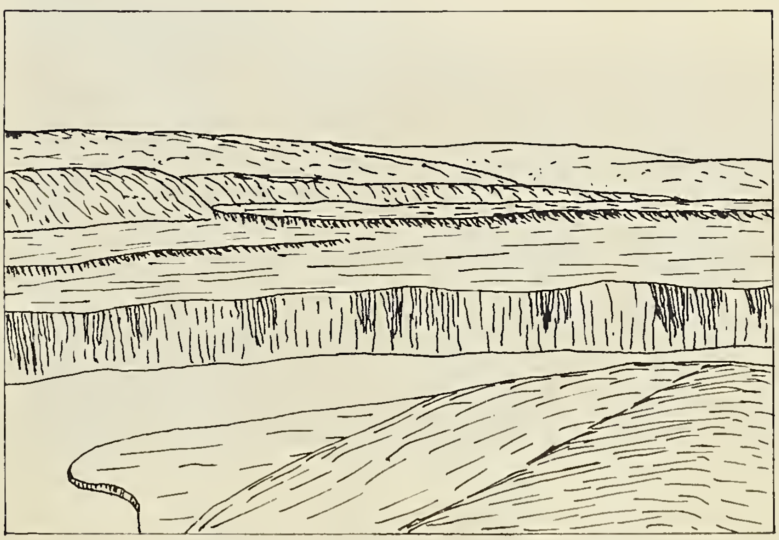

Figure 20. - Sketch Accentuoting the Glacial Feotures in the Photograph Above.

Plate 9. View northwestward of lower valley train terrace remnant on the north side of the Athabasca River across from the Hinton Pulp Mill. This flat terrace surface, at elevation 3,250 feet, serves as an airstrip for the Athabasca Valley Ranch. Note the long till "island" at the back of the terrace.

Plate 10. View southward of lower train terrace remnant west of Entrance, on south side of the Athabasca River at elevation 3,310 feet. The terrace slopes gently toward the Athabasca River from the ridge of till in the background. The clear-cutting strip resulted from North Western Pulp and Power's logging operation.

Except for parts of the downstream remnants of the lower valley train terrace, most of the remnants have steep scarp faces that rise 100 feet or more above the present Athabasca River.

Cross-sections drawn through the lower valley train terrace are shown in Figures 12, 13 and 21. Figure 13 reveals that the lower terrace remnant on the north side of the river slopes toward the valley wall in the characteristic manner of active valley trains. The surface of the terrace on the south side of the river in Figure 13, however, is nearly horizontal. Figure 21 is a cross-section of the lower terrace near the downstream end of the study-area (see Figure 14 for location). The rough surface of the terrace resulted from extensive channeling of the terrace materials by glacial meltwaters.

The lower valley train terrace in many places has a relief of over 50 feet within a distance of a few hundred yards. Like the upper terrace the large local relief is attributable to preservation of the channels and gravel bars of the original valley train surface. Erosion during creation of the lower valley train terrace, however, has contributed in some part to the large local relief, particularly in those remnants in the downstream part of the area.

Stratigraphic Units

Good exposures of the lower valley train terrace exist along the walls of gravel pits in the terrace remnant underlying Hinton Valley Town. The Canadian National Railway gravel pit, one-half mile northeast of the Hinton pulp mill, provides an exposure that is the type locality for the lower terrace materials (see Plate 11 and Figure 22). Details of the materials in this exposure are given in the following stratigraphic section:

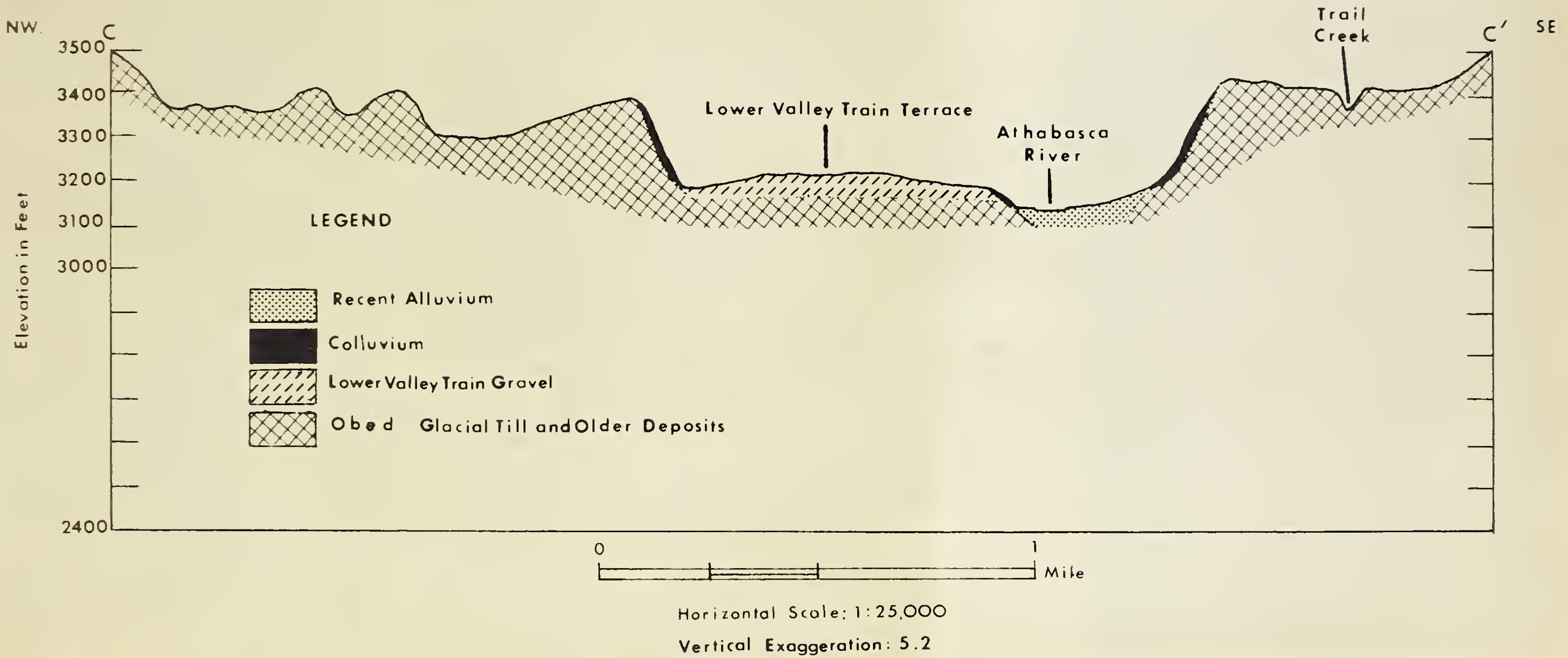

Figure 21 - Cross-section of the Athabasca Valley near Pedley showing generalized stratigraphic relationships and terrace outline.

Plate 11. Lower Valley Train Gravels Exposed at Their Type Locality in the C.N.R. Gravel Pit Below Hinton Valley Town. Northward view of locality no. 50 a.

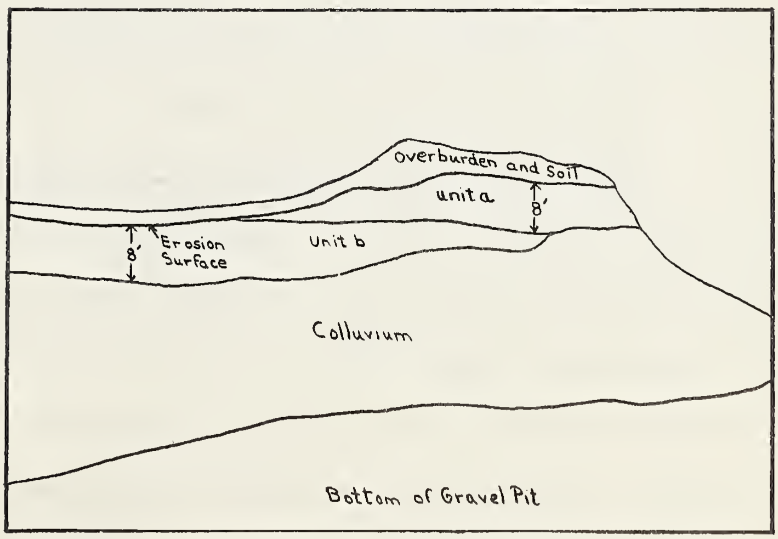

Figure 22. Diagram Accentuating the Stratigraphic Features in the Photograph Above.

TABLE IV - STRATIGRAPHIC SECTION OF LOWER VALLEY TRAIN TERRACE ON NORTH FACE OF THE EAST END OF THE CANADIAN NATIONAL RAILWAY GRAVEL PIT ONE-HALF MILE NORTHEAST OF THE HINTON PULP MILL

	Lithologic Description	Thickness in Feet
unit a:	Gravel, horizontally bedded. Individual beds are indistinct and have a uniform thickness ranging from 1 to 4 feet. Most of the gravel is subrounded and ranges up to 2 feet in diameter. Boulders over one foot comprise 5 to 10% of the unit. Some beds have no matrix. A calcium carbonate coating on the pebbles occurs in certain gravel beds. Unit a is separated from unit b by a distinct one boulder thick boulder bed.	8
unit b:	Gravel, cross-bedded, individual beds are discontinuous and short. Thickness of foresets ranges up to 3 feet. The cross-bedded foresets dip downstream at angles up to 26°. The gravel is subangular to subrounded and is heterogeneous, with large boulders often occurring in finer grained strata. The larger boulders, which comprise 1 to 2% of the unit, appear less rounded than those in unit a. The median gravel size is 1 1/4 inches. The sand matrix, comprising 10 to 20% of the unit, occurs throughout the gravel.	8
Colluvium:		

Unit a and unit b gravels of the lower valley train terrace as described in Table IV are illustrated in Plates 12 and 13.

Comparison of Upper and Lower Valley Train Materials

Although the stratigraphic units in the type localities of the upper and lower valley train terraces are generally similar (compare Tables II and IV), some differences do exist. For example, in the type locality gravels of the lower valley train, unit a is partly missing, whereas its counterpart, unit A in the upper valley train is always present. The unit a gravels of the lower valley train also tend to vary more in texture than the unit A gravels of the upper valley train. In some exposures of the lower valley train (such as site localities 54, 165, 167 and 168 in Figure 23 in Appendix B) unit a consists mainly of a layer of coarse boulders, or "lag concentration" overlying unit b gravels (see Plate 14). A "lag concentration"

Plate 12. Close-up view of lower valley train unit a gravels (locality no. 50c). Note camera as scale in centre foreground.

Plate 13. Close-up view of lower valley train unit b gravels. Note bottle as scale in centre foreground.

Plate 14. View of lower valley train gravels showing fine-grained cross-bedded unit b gravels overlain by a "lag concentration" of large boulders (locality no. 54).

covers the lower valley train terrace remnant west of Entrance.

Pebble analyses of gravel samples from the stratigraphic units of the lower valley train are shown in Table III. As with samples taken from the upper valley train terrace, median diameter pebbles were selected. Although the median size of the gravels varied from sample point to sample point, there was no definite decrease in diameter downstream.

The stratigraphic units of the lower valley train terrace could not be distinguished on the basis of their lithologic composition. However, the original reason for pebble analysis was to distinguish between the gravels of the two valley train terraces. One noticeable feature in Table III is that quartzite pebbles are less abundant and limestone pebbles more abundant in the lower terrace gravels than in the upper terrace gravels. It is questionable whether this can be used as a valid means of distinguishing between the two valley trains since only a small number of samples from the valley trains were taken and analyzed. If similar results were obtained upon analysis of a larger number of samples it would be evident that the lower valley train represented a fill brought from upstream, although there certainly was some contribution from the upper valley train materials. The higher limestone content of the lower valley train gravels could be explained by the fact the head of the valley train was near the Front Ranges where much limestone was washed down from the high mountain slopes into the valley train.[13] The large quantity of quartzite pebbles in the lower valley train gravels were derived from the melting Obed Glacier. If analysis of a larger number of samples showed there was little difference in lithologic composition be-

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[13]L.C. Peltier, Pleistocene Terraces of the Susquehanna River, Pennsylvania, Pennsylvania Topographic and Geologic Survey, Bulletin G 23, 1949, p. 79.

tween the two valley train gravels it could be rightly assumed that downstream from Entrance the lower valley train consisted mainly of reworked upper valley train gravel.

Origin

After deposition of the upper valley train the Obed Glacier retreated upstream from its still-stand near Entrance. The additional meltwaters provided by the retreating glacier reworked and terraced upper valley train material and other glacial drift in the Athabasca Valley. The terracing continued until the Obed Glacier underwent a still-stand at an undetermined position upstream of the study-area.

It was during this later still-stand that the lower valley train was formed. Terrace remnants of the lower valley train have been traced as far upstream as Brûlé Lake. Remnants might exist still farther upstream, since Mountjoy has reported terrace remnants in Jasper National Park having elevations similar to those of the lower valley train remnants.[14]

The coarse, poorly sorted, cross-bedded, unit b gravels of the lower valley train were the first to be deposited. Like the unit B gravels of the upper valley train they were deposited rapidly by swiftly flowing glacial meltwaters. The Obed Glacier meltwaters that deposited the lower valley train gravels probably gained much of their load by the erosion of morainic debris and glacio-fluvial deposits in the valley downstream from the glacier. The truncation of the downstream end of the upper valley train remnants suggests that much of the material of this valley train was supplied to streams that were building the lower valley train.

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[14]E.W. Mountjoy, unpublished manuscript that will form part of a forthcoming Geological Survey of Canada Memoir on the Miette Map-Area, Alberta, 1964.

The thin layer of unit a gravel in the lower valley train is probably channel gravel, derived from reworking of the uppermost unit b gravel by Obed Glacier meltwaters. The origin is thus identical to that of the upper valley train unit A gravel. The amount of reworking of the unit a gravels differs, however, along the lower valley train terrace remnants. A "lag concentration" of coarse boulders occurs on the remnant west of Entrance and on the upstream end of the remnant on which Hinton Valley Town is located. The presence of this "lag concentration" suggests that the coarse boulders have been sorted out and left as a residual accumulation by normal stream processes. The absence of unit a gravels in several localities suggests that the glacial meltwaters may have been sufficiently competent to transport even the largest boulders.

The resistant bedrock upstream from Maskuta Creek prevented the lower valley train meltwater streams from laterally eroding the banks, and thus the valley train did not attain a great width in this area. However, downstream from Maskuta Creek the meltwater streams depositing the lower valley train gravels were able to carve laterally into upper valley train material, glacial drift and the less resistant bedrock. As a result the remnant of the lower valley train is over two miles wide in the central portion of the study-area. In fact it was lateral erosion in this region that resulted in the destruction of most of the upper valley train.

A rapid or great change in one or a combination of hydraulic factors in the glacial meltwater streams resulted in rejuvenation of the streams and terracing of the lower valley train. A climatic change could have brought about this rejuvenation, producing melting and retreat of the Obed Glacier, which in turn altered the relative contribution of water and sediment flowing along the lower valley train. The additional quantities of water provided would then have eroded the lower valley train, thereby creating terraces.

Upstream from Maskuta Creek the lower valley train was narrowly confined within valley walls of resistant bedrock. The surface of the lower valley train remnant at Entrance contains a number of small terraces (see Plate 8 and Figure 20). The amount of valley train material deposited in this stretch was small since bedrock lies close to the surface over most of the remnant. The small terrace on the hill behind Entrance probably marks the original level of the valley train fill. Subsequent erosion by meltwater carved a minor series of terraces, each of which is mantled by a thin layer of gravels.

The rapid rejuvenation of the glacial meltwaters following the retreat of the Obed Glacier brought about the paired terraces of the lower valley train in the central portion of the study-area. Since terrace formation, the Athabasca River in this region has continued to flow in a non-meandering channel resulting in there being little destruction of the lower valley train terrace remnants.

At the downstream end of the study-area the glacial meltwaters meandered as they terraced the lower valley train. Consequently, there was much channeling and erosion of the lower valley train, producing a large local relief (see Figure 21). A northward meander of the Athabasca River in late glacial and recent times has produced a smooth slip-off slope on the downstream end of the terrace remnant on the north side of the river (see Figure 11).

Age of the Valley Train Terraces

The surficial deposits in the study-area have not been dated and no definite correlation has been established with other glacial deposits in the region. From general reconnaissance mapping, it is tentatively believed that the Obed Glacier, whose meltwaters formed the terraces, is probably late Wisconsin in age.

CHAPTER V

SUMMARY AND CONCLUSIONS

There have been at least two advances of Cordilleran ice within the study-area. The glacial advances, which are represented by distinct till sheets, are believed to have occurred during the late Wisconsin period. The till sheets can be separated on the basis of composition, stratigraphy and geomorphology.

The oldest Cordilleran glacier was a piedmont glacier that extended far down the Athabasca Valley to the northeast and covered the divide areas northwest and southeast of the study-area. Mainly by means of back-wasting the piedmont glacier eventually retreated at least as far as the Front Range of the Rocky Mountains, leaving in its wake glacio-fluvial and glacio-lacustrine deposits known as the pre-Obed sediments.

The last glacier to enter the area was the Obed Glacier, an expanded toe-valley glacier that almost filled the Athabasca Valley as far east as Obed. The position of the Continental Glacier with respect to the advancing and retreating Obed Glacier is not known. However, the extensive glacio-fluvial materials deposited in the Athabasca Valley upon retreat of the Obed Glacier attest to the fact that meltwater drainage down the valley was not obstructed by Continental ice. The absence of ice-contact glacio-fluvial deposits and end or recessional moraines between Entrance and Obed suggests that the Obed Glacier underwent rapid frontal retreat in this stretch of the valley.

Near Entrance the Obed Glacier underwent a prolonged still-stand, pro-

ducing a recessional moraine that, although lacking the normally associated ridges of till, contains pitted outwash, eskers, and other ice-contact glacio-fluvial deposits.

It was during this still-stand that the upper valley train was formed. Two stratigraphic units comprise this valley train. The lower unit, unit B, was the first to be deposited. The coarse, poorly sorted, subangular to sub-rounded, and cross-bedded nature of the gravels suggests that aggradation was by rapid, widely fluctuating glacial meltwater streams. The upper unit, unit A, is better sorted and horizontally bedded, and is likely channel gravel which resulted from reworking of the uppermost unit B gravels by glacial melt-waters. Rapid retreat of the Obed Glacier from its still-stand position near Entrance provided additional quantities of meltwaters that probably not only reworked the upper valley train materials but produced sufficient flow to erode and form the paired upper valley train terraces of the study-area.

Terracing of the upper valley train continued until the Obed Glacier underwent a still-stand at an undetermined position upstream. It was during this still-stand that the lower valley train was formed. Like the upper valley train, the lower valley train is comprised of two stratigraphic units. The lower unit, unit b, is similar to unit B of the upper valley train and likewise was deposited by swiftly flowing glacial meltwater streams. The unit a gravels of the lower valley train, like unit A of the upper valley train, are probably channel gravels that resulted from reworking of the uppermost part of unit b. Unlike the unit A gravels of the upper valley train, the amount of reworking of lower valley train unit a gravels varies from place to place. In some places there is a "lag concentration" of coarse boulders, while elsewhere unit a is entirely missing. Both examples show that glacial meltwaters may have been competent enough to move even the largest boulders. To the writer's knowledge no studies have been made

of valley trains displaying the same stratigraphic characteristics as those described in this study.

The retreat of the Obed Glacier from its undetermined still-stand upstream of the study-area resulted in erosion and formation of the lower valley train terraces. Large paired terrace remnants of the lower valley train occur in the central portion of the study-area. Upstream from Maskuta Creek the lower valley train was narrowly confined within valley walls of resistant bedrock and the terrace remnants produced are small and consist of a thin layer of gravel overlying bedrock. In the downstream end of the study-area the glacial meltwater streams meandered as they dissected the lower valley train. As a result there was much channeling and slip-off slope development of the lower valley train.

The study has been an attempt to interpret the large terraces along the Athabasca River in the vicinity of Hinton, Alberta. The terraces are believed to be valley train terraces formed during the retreat of the Obed Glacier, the last glacier to occupy the area. The existence of terraces farther upstream along the Athabasca and tributary valleys warrants further study in order to fully interpret the late Pleistocene history of the region.

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APPENDIX A

TABLE V - WATER BALANCE EQUATIONS FOR ENTRANCE, 1921-1950[1]

Year	Ppt.	=	PE	-	Def.	+	Str.	±	St. Change[2]
1921	14.5	=	19.5	-	5.9	+	1.7		- 0.8
1922	10.9	=	20.6	-	9.4	+	0.0		+ 0.3
1923	14.6	=	19.1	-	4.9	+	0.0		+ 0.4
1924	13.6	=	19.6	-	7.9	+	0.0		+ 1.1
1925	22.6	=	20.0	-	1.9	+	3.2		+ 1.3
1926	19.1	=	20.1	-	3.5	+	2.5		
1927	22.5	=	19.6	-	0.0	+	2.9		
1928	21.5	=	16.2	-	0.0	+	5.3		
1929	18.2	=	18.9	-	4.3	+	4.6		- 1.0
1930	15.5	=	19.4	-	2.7	+	1.8		- 3.0
1931	23.6	=	22.0	-	1.0	+	0.0		+ 2.6
1932	20.3	=	19.8	-	1.5	+	0.6		+ 1.4
1933	27.3	=	18.8	-	0.7	+	4.2		+ 5.0
1934	26.1	=	20.3	-	0.0	+	5.8		
1935	31.0	=	19.3	-	0.0	+	11.7		
1936	14.8	=	22.0	-	6.7	+	2.9		- 3.4
1937	14.2	=	20.6	-	8.0	+	0.0		+ 1.6
1938	17.9	=	21.0	-	1.7	+	0.0		- 1.4
1939	14.6	=	20.6	-	6.5	+	0.0		+ 0.5
1940	16.6	=	20.0	-	4.8	+	1.4		
1941	19.6	=	21.1	-	2.0	+	0.0		+ 0.5
1942	24.5	=	20.1	-	0.0	+	2.2		+ 2.2
1943	15.7	=	22.3	-	5.3	+	2.1		- 3.4
1944	28.6	=	20.5	-	0.0	+	6.5		+14.6
1945	*								
1946	14.6	=	20.4	-	8.2	+	2.9		- 0.5
1947	21.1	=	20.1	-	0.7	+	1.6		+ 0.1
1948	24.5	=	20.1	-	2.8	+	6.8		+ 0.4
1949	*								
1950	18.1	=	19.6	-	5.1	+	2.2		+ 1.4

*Data not available for several months

[1]Based on Thornthwaite procedures of 1948

[2]Abbreviations used: ppt. - precipitation; PE - potential evapotranspiration; def. - deficit; str. - streamflow; st.change - storage change

Source: A.H. Laycock, unpublished data

TABLE VI - CLASSIFICATION OF SOILS OCCURRING IN STUDY-AREA

Order	Great Group	Sub-group
Podzolic Soils Well and imperfectly drained soils developed under forest having light coloured eluviated horizons and illuviated horizons with accumulations of sesquioxides, organic matter or clay, or any combination of these.	Grey-Wooded Soils Soils with organic horizons (L-H), with light coloured eluvial horizons and with illuviated horizons in which clay is the main accumulation product. Developed on basic materials. The solum generally has a medium to high degree of base saturation.	Bisequa Grey Wooded Soils Grey wooded soils in which a podzol sequence of horizons has developed in Ae and overlying a continuous texture (Bt)horizon at depths of less than 30 inches from the surface. If the solum of the podzol sequence is well developed (orthic) it must be less than 18" thick.
	Podzol Soils Soils with organic horizons (L-H), with light coloured eluvial horizons and illuviated horizons in which organic matter and sesquioxides are the main accumulation products. The solum is generally moderately to strongly unsaturated.	
Brunisolic Soils Well to imperfectly drained soils developed under forest or mixed forest and grass vegetation with brownish coloured sola without marked eluvial or illuvial horizons.	Brown Wooded Soils Soils of high base saturation without distinct Ah horizons.	
Gleysolic Soils Soils with organic horizons (up to 12 inches thick) or with an Ah horizon or with both, or without these surface horizons but some organic material dispersed throughout the mineral soil. The subsoils show gleying and are dull coloured but may have brighter coloured prominent mottles. Soils associated with wetness. They have developed under various		

Table VI, contd.

climatic and vegetative conditions and in the presence of a high or highly fluctuating water table.	
Organic Soils Soils that contain at least 20% organic matter, are 12" or more in depth and have no horizon development in the mineral substratum other than gleying.	

Source: National Soil Survey Committee of Canada, 1960.

APPENDIX B

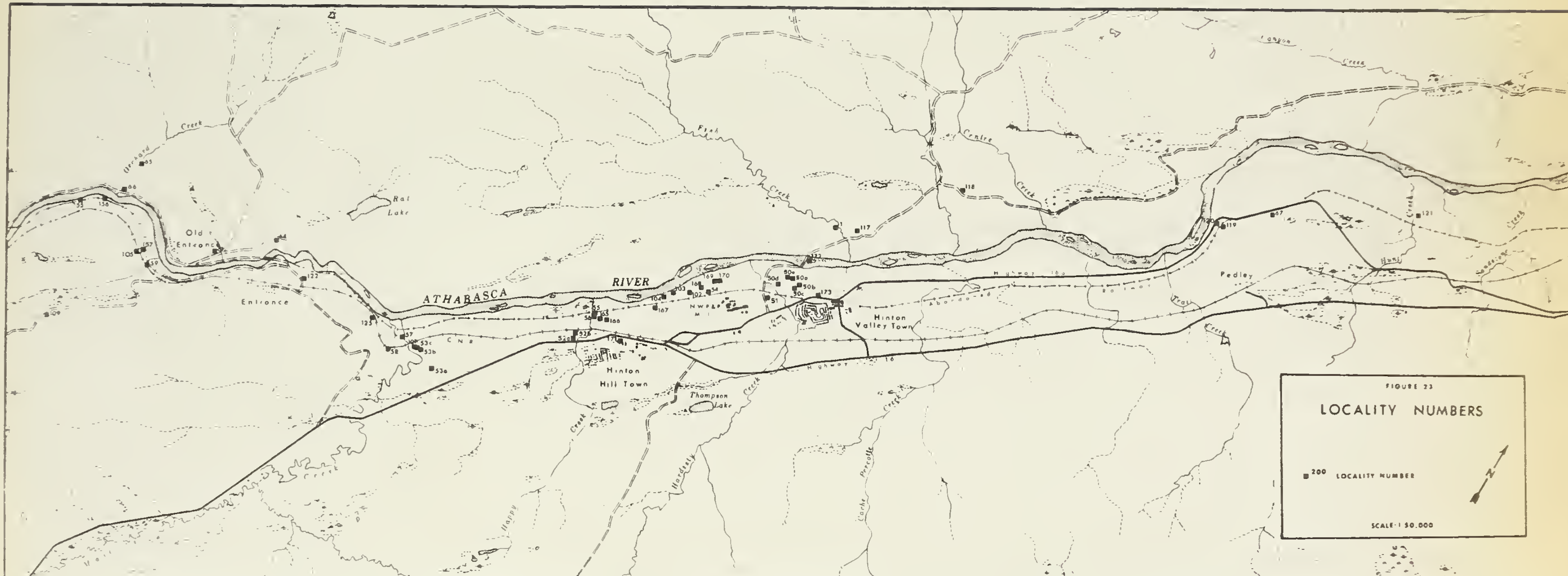

FIGURE 23

LOCALITY NUMBERS